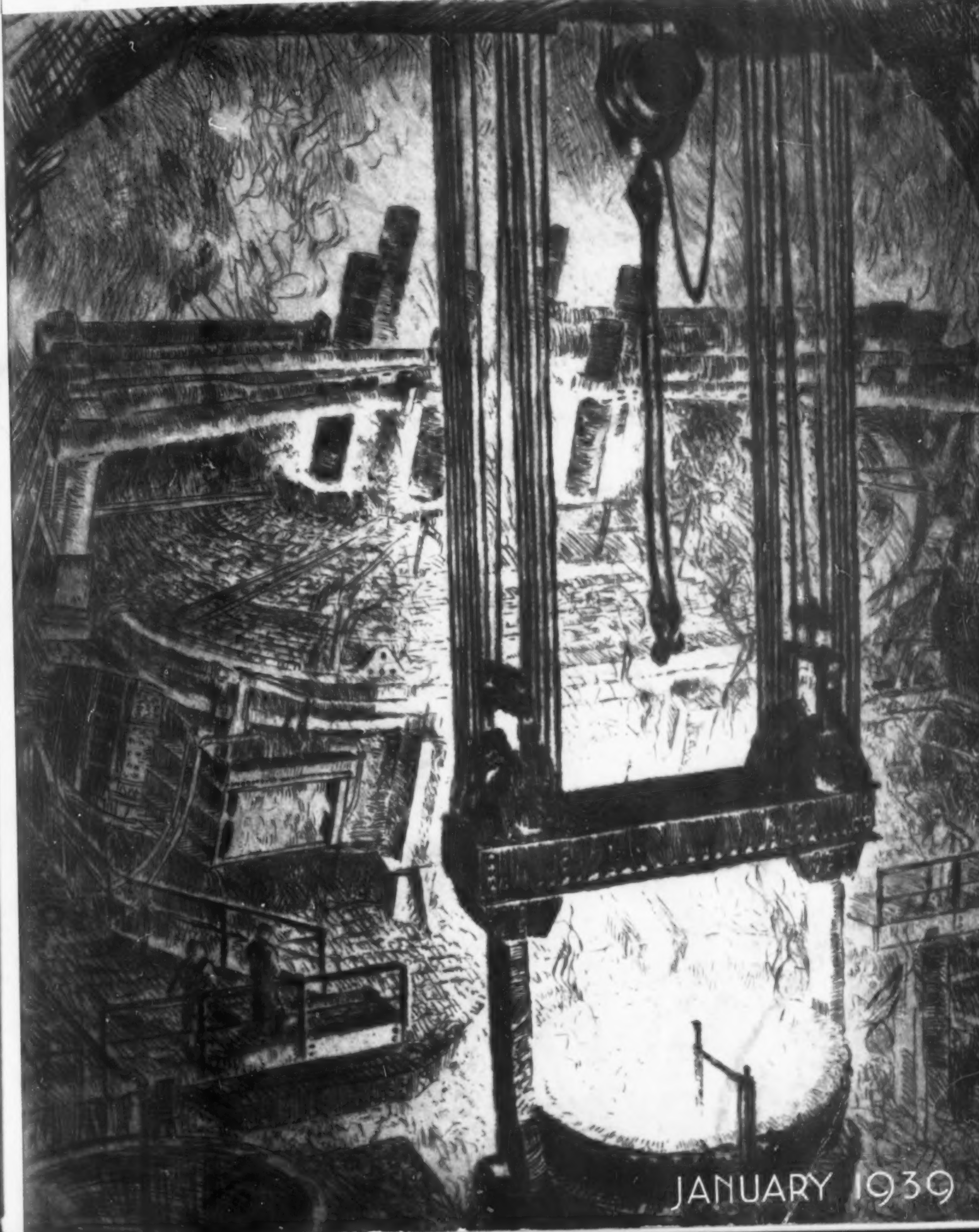
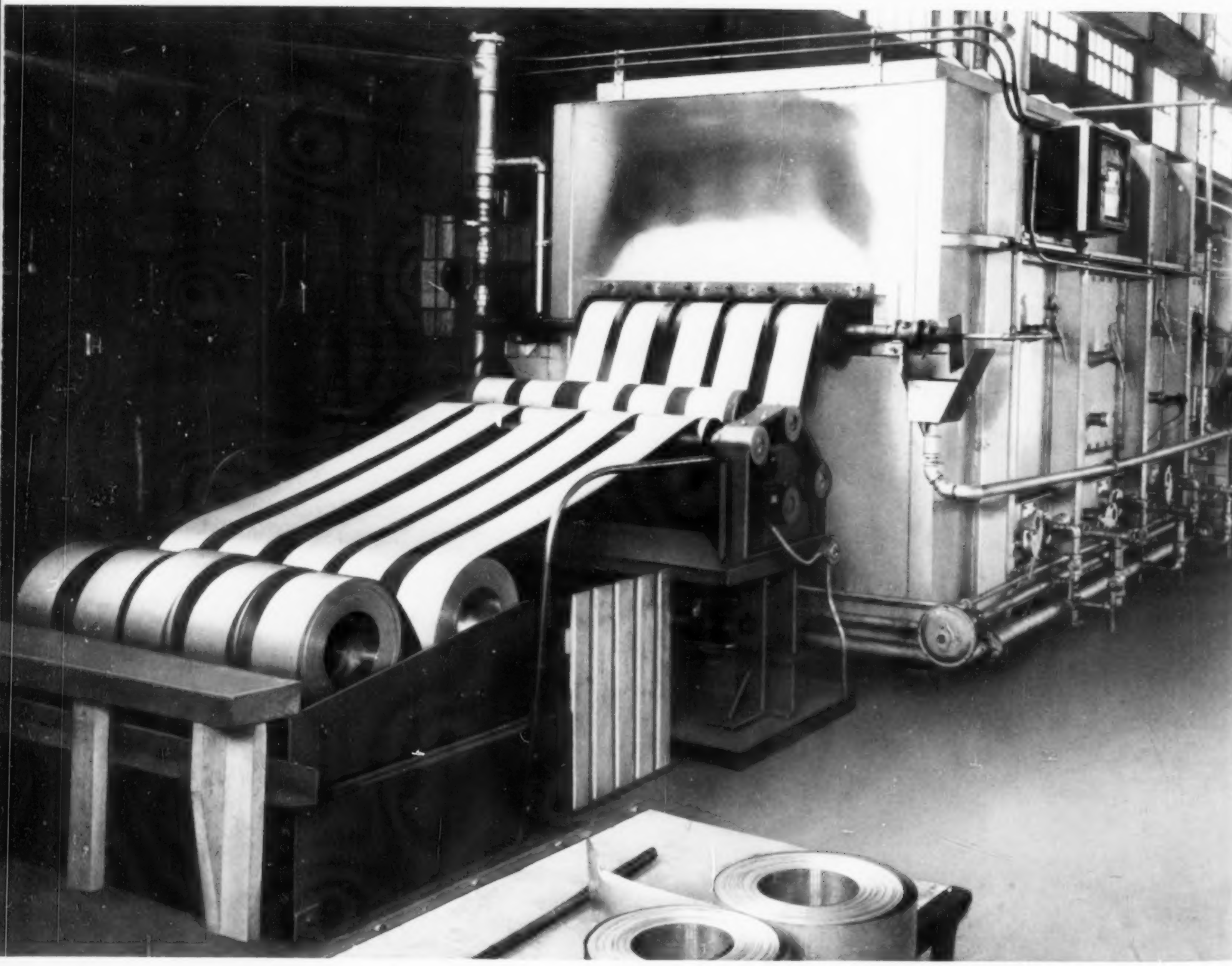
Metal PROGRESS





METAL PROGRESS

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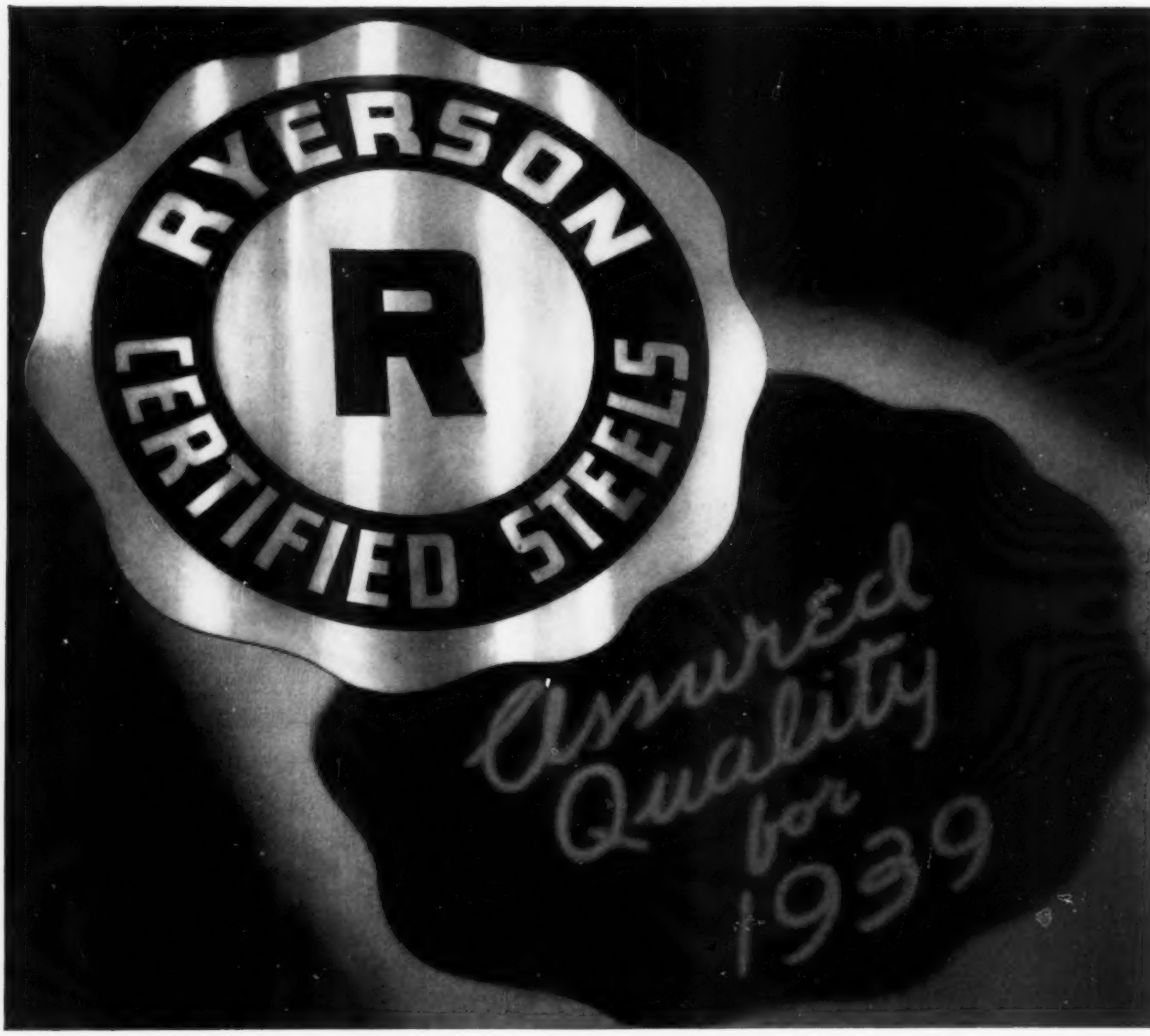
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METAL PROGRESS

January, 1939 — Volume 35 Number 1

HARDENABILITY OF STEEL

growth of the concept

By Robert S. Archer
Chief Metallurgist
Chicago District
Republic Steel Corp.

THE HARDENABILITY PROBLEMS of today have arisen largely as a result of the development of modern manufacturing methods. Until about 25 years ago, the heat treatment experts were the tool hardeners. Many of these men knew the importance of the degree of hardness, the penetration of hardness, and the fineness or coarseness of the fracture. They knew that different lots of toolsteel of the same carbon content behaved differently in these respects, and perhaps others, and ascribed such behavior to a mysterious quality known as "body", supposed to be determined at least in part by the kind of material used as melting stock. Much, but not all, of this quality of toolsteel called "body" is really comprised in what we now call "hardenability". (Note that "body" was associated with raw materials and melting practice, and hence with individual melts or heats of steel.)

It was largely the growth of the automobile industry, and then the World War, which resulted in the mass production of heat treated parts made of hypo-eutectoid steels. Mass production meant the purchase of steel in heat lots. It also developed equipment and methods for treating large numbers of pieces of the same shape and size according to definite cycles of time and temperature. Such uniform treatment should have produced uniform properties, providing all pieces of steel bought to the same chemical specifications had behaved alike in heat treatment — but they did not. Nor did the variations in chemistry permitted by the specifications seem to explain the observed differences. An early comment of interest in this connection is that of H. C. Loudenbeck in the first volume of our own *Transactions* who, in an article on "Necessary Precautions to Obtain Uniformity in the Heat Treatment of Steel", attributed the failure of a certain heat of 0.36% carbon steel to harden as well as usual to the presence of "more than traces of aluminum".

It was the early work of McQuaid and Ehn discussed at length on page 43 of this issue on the cause of soft spots in carburized parts which led to intensive studies of steel making and steel

application. They found that soft spots after hardening were associated with a certain form and distribution of the carbides in the case and described this structure as "abnormal". It was soon recognized that their "abnormal" structures were often associated with fine grain. Steels began to be rated according to "grain size" as found in the McQuaid-Ehn test (Metals Handbook, p. 580). Steels of the "fine-grained type" were known to harden less deeply than "coarse-grained" steels of the same composition with respect to elements commonly determined. Other generalizations were proclaimed which were, perhaps, too broad to be true without some qualification. Among these are: "Fine-grained steels" show (1) smaller distortion, (2) greater toughness in impact, (3) poorer machinability, (4) more rapid spheroidizing, and (5) less rapid carburizing.

Note again that the "inherent grain size" was usually considered a characteristic of a heat of steel. Steel mills rather quickly learned how to make steel of the coarse-grained or fine-grained type, as judged as the McQuaid-Ehn test. The methods employed were not at first made public, but it soon became known that the fine-grained type was made by adding more aluminum, usually to the ladle. At least one steel melter, John McConnell at Interstate Iron & Steel Co., Chicago, was consistently using large aluminum additions in 1919 to make his steel "tough", although he probably didn't consider his results in terms of austenite grain size.

Bain and his associates, in an article "General Relations Between Grain Size and Hardenability and the Normality of Steels" in *Transactions* , 1934, have shown that it is the *austenitic* grain size at the time of quenching, rather than the *inherent* grain size of the McQuaid-Ehn test, that determines the depth of hardening on quenching a steel of given analysis. For this and other reasons the American Society for Testing Materials has tentatively established a specification to determine grain size at normal hardening temperatures (see last month's Metal Progress, page 695), but the McQuaid-Ehn test at 1700° F. is still generally used. Steel rated fine grained in the latter test is also fine grained at the lower hardening temperatures, and therefore behaves as expected. Steel rated coarse at 1700° F. may, however, be fine at low hardening temperatures, and may therefore harden less deeply than expected. There are many who do not believe that the depth-hardening property of steel is entirely determined by ordinary chemistry and austenite grain size, even when this grain size is determined for the actual hardening conditions later to be used.

> *It used to be said that a steel had "body" if it hardened deeply and recovered toughness on tempering, and this quality was supposedly the result of undefined "good practices" in steel making. Past-President Archer now tells how some of this fog has been cleared by correlating the refining and ingot practice with hardness measurements across a quenched sample of the resulting steel and with its metallography.*

Until recently, the effects of chemical composition and of austenite grain size had been known only in a qualitative way. Many metallurgists therefore carried out actual hardening tests on each heat of steel before using it for work requiring close control of hardenability, usually on specimens similar in size to the parts to be made and duplicating as nearly as possible the heating and quenching conditions of the particular commercial practice. Results were appraised by measuring the hardness at the surface, at the center, or at half-radius. Such tests resulted in the accumulation of a great deal of specific and uncorrelated data. A steel found suitable, or otherwise, for a particular part with respect to hardenability, could not with assurance be approved or rejected for some other machine part.

It was evidently with these conditions in mind that two papers were presented at the 1937 Convention. One entitled "A Hardenability Test for Carburizing Steel" by Boegehold and Jominy offered a method for the quantitative determination of hardenability and gave results for many steels, mostly of the alloy carburizing type. It was pointed out that the quenching rate necessary to develop full hardness in the carburized case particularly of S.A.E. 4620 (1.75 Ni, 0.25 Mo) was not adequately indicated by chemical analysis and grain size. The other paper on "Quantitative Hardenability" by Burns, Moore and Archer proposed another type of test for

the quantitative determination of hardenability and gave results for many plain carbon steels of various carbon contents. These authors concluded that for steels of this type, given a prior normalizing treatment, the hardenability could be predicted from chemistry and grain size with a degree of accuracy satisfactory for most practical purposes. Grain size was determined at the time of quenching as well as at 1700° F. The study did not cover carburized specimens.

The terms "hardness" and "hardenability" have been used above without definition. If further evidence were needed that "hardness" is not a fundamental property, it was amply supplied in the "round table discussion" on hardness and hardness testing at the last convention, which drew editorial comment in Metal Progress in November (page 554). It is well known, of course, that our various "hardness" tests measure complex combinations of properties and hence do not parallel each other exactly. We have seen specimens of steel with Rockwell C values in the fifties which are file hard, while others can be filed at 60 or higher. In studying the hardening characteristics of steel we must, therefore, remember that results expressed in terms of a specific "hardness" test might not find exactly parallel expression in terms of some other test. We would perhaps avoid some confusion if we would refer to the various tests merely by name without mentioning hardness, giving only Brinell *numbers*, Rockwell *numbers*, scleroscope *numbers*, and so on.

The term "hardenability" likewise cannot be defined as a definite fundamental property of a steel, at least for the present. The duty of the lexicographer is not to create the meaning of a word, but to record the meaning or meanings intended by those who use it. This meaning is not yet stabilized or consistent. To some, hardenability means surface hardness; to others, the ease of obtaining a surface free from soft spots; to others, the depth of hardening. This depth may mean the depth of full hardening, the depth shown by etching, or the depth at which a certain Brinell or Rockwell number is reached.

It was shown by Burns, Moore and Archer in the paper last mentioned that the Rockwell C value for martensite is determined by its carbon content and is affected very little by its content of small amounts of the alloy elements. It is now possible to determine the *maximum* Rockwell C value for a steel merely from its carbon content. The tendency for the steel to form a fully martensitic structure at any given point, including the surface, depends, however, on those factors which affect depth of hardening. Hence, many would like to include some measure of surface hardness in their conception of hardenability.

In view of the facts that despite improved steel making control there are occasional heats that do not harden in the expected manner, that various tests are in actual use to determine hardenability, that even the nomenclature is somewhat confused, and that fundamentally new concepts have been established on the mechanism of hardening, especially of transformation at constant, elevated temperature, a timely series of discussions was organized at the Convention in Detroit last fall. This Symposium on Hardenability will be reviewed at considerable length in a pair of articles in succeeding issues of Metal Progress.

LIGHT WEIGHT FREIGHT CARS

of high strength, low alloy steel

By Ernest E. Thum
Editor, Metal Progress

RAILROAD MEN generally are keenly aware of the fact that the average pay load in freight cars tends to decrease steadily. Innumerable less-than-carload consignments are now carried by the automobile truck, yet the proportion of cars in LCL traffic has not decreased proportionately. Some of the bulk commodities like coal are being handled in smaller lots, purchasers declining to carry any more than enough for immediate needs. The trend toward small loads has therefore required extraordinary efforts to combat. For instance, car loadings in Class I railroads steadily decreased from an average of 29.3 tons per car in 1920 to 25.6 tons per car in 1933, and then recovered slightly to 26.0 tons in 1935, 26.8 tons in 1936 and 27.1 tons in 1937. Meanwhile the weight of the average car had increased from 20.1 tons in 1920 to 22.8 tons in 1933 and 23.7 tons in 1937. Less freight was being hauled in bigger, heavier cars.

Faced with this trend, the operating men endeavored to perform more transportation service with each car by speeding up the trains (15.9 miles per hr. for freight trains in 1933 against 11.9 in 1920), but the ratio of car weight to contents was so high that it became obvious that too much dead weight was being hauled around the country.

Such a situation forms the background for a statement in 1934 from Railroad Coordinator Eastman, containing the following specification for a modern freight car:

"It must weigh less than a fifth of its maximum load but be strong enough to pull 1000 times its own weight.

"It must be designed to carry any kind of freight anywhere any time.

"It must be made shock-proof by various cushioning devices.

"It must reduce friction by some form of roller or ball bearings.

"It must have facilities for loading and unloading from any one of the six sides.

"It must be so constructed that the car body can be transferred easily to a truck chassis."

Such an all-purpose car is admittedly ideal (railroad men might call it "surrealistic") and some attempts to design cars to fulfill simultaneously more than two of these objectives, at a price, have failed. However, there was some chance that the first specification could be approached, namely, load five times the weight, for the railroads had carefully studied designs and had passed the 3 to 1 ratio with mild carbon steel. The 5 to 1 goal could probably be reached if and when the steel industry could offer corrosion resistant materials of higher strength at reasonable cost. Competing transport on highway and in the air had already developed the principles of light weight design

and construction, and the metal industry was furnishing the necessary metals of high strength/weight ratio, but it was all but impossible to adapt this to railroad practice, nor was the money forthcoming to pay the large premium for such special materials.

Even though railroad men could not accept radical and expensive innovations — especially if non-interchangeable with existing equipment — they had long been studying the problem of a standard freight car through the American Railway Association — now the Association of American Railways (A.A.R.). Its Committee on Car Construction had carefully analyzed the design of a box car and in the late 1920's about 30,000 of these standard cars had been built. Gondolas and hopper cars were also under careful scrutiny by 1930. It must be said, however, that in these studies the emphasis was upon refining the design, eliminating proven points of weakness, and stiffening the floor system and center sill, rather than upon saving any weight in truck or car body. Low carbon structural steel was the accepted material; allowable unit stresses were based on 16,000 psi. safe load in tension, and no allowance was made for the impact of buffing other than a requirement that the center sill must stand an end load of 250,000 lb., which approached the elastic limit of coupler and drawbar. Load limit (pay load plus car) was set by interchange rules at 169,000 lb. on four axles with 5½×10-in. journals.

> *ELABORATE tests and experience indicate that a superior freight car can be built at competing prices weighing 5 tons less than conventional designs, and over 10,000 have already been built. About one quarter of all new and rebuilt cars use some of the high strength, low alloy steels in body or underframe.*

As a result of these studies, reported to the A.A.R. in 1932, it became apparent that no more than about 3500 lb. could be shaved off the War-time box car by refinements in design. Since the loading and impacts in service were getting greater rather than less, any further substantial saving in dead load could come only through the use of stronger metal. Fortunately the steel industry at this very time, at the request of the car builders, was able to offer a variety of new low alloy steels of improved strength and corrosion resistance, easy fabricating properties and good weldability, and of relatively low cost. This seemed to be exactly what the situation demanded.

Engineering developments therefore were rapid. The first really light weight cars, aside from those with aluminum bodies for restricted service in the chemical and allied industries, were two gondolas and one box car built by the Baltimore and Ohio in its own shops early in 1934, of a corrosion resisting, high tensile steel called "Cor-ten", made by the U.S. Steel Corp. In the fall of the same year Pressed Steel Car Co. made 100 hopper cars of the same steel; Mt. Vernon Car Mfg. Co. also built a refrigerator car with about 7900 lb. of plain carbon steel replaced by 5300 lb. of a stronger, medium manganese steel (a saving of 2600 lb.). The B. & O. cars were lighter than these, the hopper car weighing 31,200 lb. for a load limit of 137,800 (total 169,000 lb.) instead of 41,500 for the A.A.R. car to carry 127,500 lb., and the Pressed Steel Car Co.'s cars even lighter yet (30,000 lb. for 139,000 load limit). Since the loaded weight was the same (169,000 lb.), it resulted that the ratio, pay load to dead load, was 4.4 for the B. & O. car and 4.6 for the Pressed Steel Car Co.'s cars instead of 3.1 to 1 for the equivalent A.A.R. cars of plain carbon steel — a measurable approach to Coordinator Eastman's goal of 5 to 1.

Next year, 1935, Pullman-Standard Car Mfg. Co. built a steel sheathed, wood lined box car using the A.A.R. standard dimensions and computation methods, except that it was figured for a high tensile steel whose yield point was two thirds greater than low carbon steel. Likewise three quarters of the seams were welded. Having in view a probable revolution in car building materials and methods, this company desired to determine *(a)* the suitability of the new steels to ordinary shop fabrication, *(b)* the soundness of certain new principles of design, *(c)* the practicability of welding and *(d)* the costs in relation to the standard A.A.R. car. What was desired was a car equal in strength in all details to the standard car, and by use of stronger metals the following changes could be made:

	1935 Pullman Box Car	Standard A.A.R. Box Car
Area of center sill	16.96 sq.in.	21.20 sq.in.
Thickness, side sheets	0.05 in.	0.10 in.
Thickness, end sheets	$\frac{1}{8}$ in.	$\frac{1}{4}$ in.
Thickness of roof	0.05 in.	15 gage galvanized
Weight of trucks	13,960 lb.	15,700 lb.
Weight of car body	20,240 lb.	28,400 lb.
Total dead load	34,200 lb.	44,100 lb.
Cubic capacity	3384 cu.ft.	3311 cu.ft.

In the trucks 680 lb. was saved by using the light weight, chilled iron wheels recommended by Association of Chilled Car Wheel Manufacturers. Couplers and yokes were of high tensile cast steel. Considerable rigidity and strength was achieved by attaching stiffeners, diaphragms and tie plates (by welding) at intersections of body bolsters, end sills, and floor beams with the center sill, thus making all crossmembers continuous beams. In short, many conventional features of construction were disregarded and specialties (such as patented doors, end designs and roofs) eliminated wherever possible.

Mt. Vernon Car Co. also made a box car of high strength steel over the A.A.R. computations and with riveted construction throughout. In effect this was an A.A.R. standard box car, scaled down in thickness of steel sheets and sections to take advantage of the added strength of the alloy steel. It weighed a total of 36,400 lb. By comparing with the special welded car just described, riveted construction was apparently responsible for a ton of extra details.

These cars were tested by measuring the relative position of nearly 400 reference points when the car was empty, loaded to capacity, and after being struck by a standard car (also loaded) at various speeds from 2 to 16 miles per hr. The riveted car behaved rather better than the welded one, and after minor repairs for damages received at high speed impact the Mt. Vernon car was put into regular railroad service where it still is.

The A.A.R. committee reported on these tests on the Pullman welded car as follows:

1. Static deflections were greater in the light car than in the A.A.R. standard design, as would be expected from the smaller sections and heavier loads, but not beyond satisfactory limits.

2. Some failures after impact at welds and in

The Railroad Still Carries the Freight, Most Trains Being Operated on Schedules Almost as Rigid as Passenger Trains. Photo courtesy Pennsylvania Railroad

end plates were due to improper welding technique and inadequate design which can easily be avoided.

3. Roof and side sheets buckled on account of insufficient stiffness (stiffeners placed too far apart in the 0.05-in. sheet).

4. Coupler and shank is not stiff enough—its bending under impact caused much damage to the underframe.

Utilizing the information gained in this way, a careful revision was made in the design of details and another box car was made by Pullman-Standard in 1937 with welding equipment developed especially for this service and shown in the views on the next two pages, and tested in a similar way. However, in these tests the stresses were measured by 121 deForest strain gages attached to the structure. Numerous impact tests were made on this car, loaded to capacity, and struck by a loaded A.A.R. 1932 car at speeds up to 13.3 miles per hr. (an exceedingly destructive test). Official findings may be summarized as follows:

The stresses under impact are about the same at corresponding points in both the welded and the heavier standard cars, but are lower in proportion to the yield point of the alloy steel used in the lighter car. (Yield point in the strong steel is 50,000 psi., and 30,000 psi. in the carbon steel.) The highest stressed point in the underframe exceeded the yield point at 9.8 miles per hr. impact in the light car, and at 7.8 miles per hr. in the standard car. Coupler shanks reached their yield point at impacts of 4.5 miles per hr. The standard car is figured with a 250,000-lb. load at the ends of the sill; this computed allowance was exceeded at the lowest speed of impact (2.1 miles per hr.) and mounted to 675,000 lb. at 10.8 miles per hr. Since actual stress measurement is a better basis for design of main members and details to resist buffing stresses, the latter are found to be very much greater than the static stresses assumed as the basis of the old design.

Since there was no evidence of failure or distress at any of the welds, the Committee certified that the light weight welded car was at least as good and safe a car as the A.A.R. standard car. Likewise the car builder stated that it would *cost* no more than the conventional riveted car (due in part to less raw material, in part to economical construction in a newly built plant on a production line basis, and in part to the elimination of patented auxiliaries and associated royalties).

Progress toward the light car may be summarized in the attached table, where the loaded weight is the same in all instances and 169,000 lb. Note also that the box car is relatively heavier than the open top hopper cars mentioned earlier in this article; also note the great improvement in weight as measured in terms of volume, since much freight is too bulky to develop the load limit.

Progressive Weight Saving

Box Car Design	Date	Light Weight	Ratio Pay Load / Dead Load	Lb. per Cu.Ft. Capacity
U. S. Railroad Administration	1918	47,600	2.55	15.37
A.A.R. standard	1932	44,200	2.8	13.35
B. & O. R. R.	1934	37,500	3.5	11.06
Mt. Vernon Car Co.	1936	36,400	3.54	10.99
A.A.R. large car	1937	45,300	2.73	12.27
Pullman-Standard*	1937	35,300	3.8	9.51

*Same inside dimensions as A.A.R. large car (1937).

It would appear demonstrated that new cars are now available to American railroads which weigh nearly 10,000 lb. less than the existing ones. On the basis of 11,000 miles per car per year at 1 mill per ton-mile (both conservatively estimated by Ralph Budd, president of the Burlington Lines), the new light cars would theoretically cost $55 per year less to operate than heavy ones—although the savings would probably not be visible on the ledgers until a considerable fraction of the equipment were converted. However, it should certainly not result in any *increase* in coal bills, and since the cars can be had at no additional first cost, there is a certain advantage to be gained from the added pay load per car that would frequently be possible.

Are the railroads interested?

The answer depends on the viewpoint.

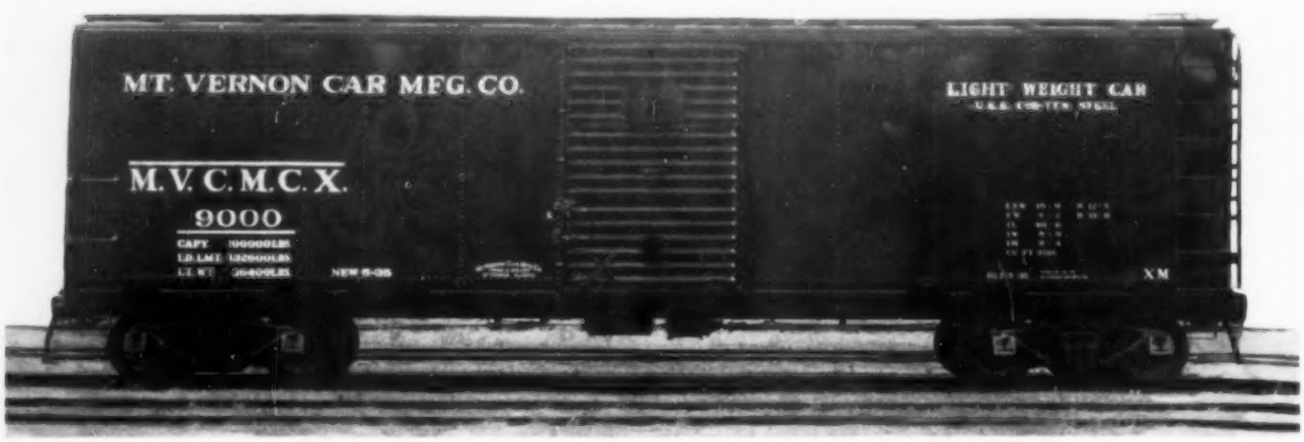
A report of the Committee on Car Construction to the Association of American Railroads shows that a total of 77,270 new freight cars were put into service between April 1, 1936 and May 25, 1937. Of these 150 were light weight box cars and 1700 were light weight hopper cars. However, these figures merely include cars built to the A.A.R. basic design. More recently 200 box cars, all welded, were built by

Pullman-Standard, primarily for testing under service conditions on a number of Class I railroads. Mt. Vernon Car Mfg. Co. built 900 freight cars of alloy steel in 1937, including 500 automobile cars for the Chicago and Northwestern Railway Co. each saving 7900 lb. from the original design. The Milwaukee Railroad and the Union Pacific also scheduled a notable number of alloy steel cars for their own shops (1500 and 2600 respectively). At least 4000 other cars, each saving on the order of 4 tons, have been built to designs other than the A.A.R. standard.

As a whole, however, this grand total of perhaps 10,000 cars in two years is not an impressive record for the American railroad industry, which should replace about 100,000 cars every year, just to keep abreast of deterioration in their 2,000,000 units. It is almost impossible to estimate the number of cars, including those being currently rebuilt or extensively repaired, which are using considerable quantities of high strength steels. Certain it is that the railroads have gone further in the adoption of these new materials than any other industry.

A more encouraging sign is that a sizable fraction of all new cars, say one quarter of them, now have *some* high tensile steel in them. Present practice tends toward the use of thinner sheets of high tensile steel of good corrosion resistance on the sides, which saves a little weight as easily as possible. Of course, there are numerous other designs where the special steels have been used in the underframe where standard car steel was used in the sides. Likewise 50 different designs of light weight carbon or alloy steel truck side-frames and bolsters have been approved since early 1936 by the A.A.R. and at least 20,000 cars so equipped.

A little arithmetic will indicate the economics of the case — mild carbon steel versus high strength, low alloy steel — assuming no extra fabrication expense: The base price of a typical low alloy steel is roughly 45% more than mild carbon steel, copper bearing; however, the inevitable extras for size, finish, straightness and special sections are the same (per pound) so the actual cost is about one third more. If the side sheets in an open-top car can be cut from $\frac{3}{16}$-in. carbon steel to $\frac{1}{8}$-in. alloy (as they can be safely — and are — when the corrosion resistance and yield point are twice as high), there is a 9% saving in the first cost of the steel going into these portions of the car. Lighter steel means more adequate stiffening, and this would make the two designs break about even in cost. In box cars (wood sheathed) the side sheets may be 0.06 in. instead of 0.10 in. and the saving in cost is higher — 21% on these details. Under these circumstances it is obvious why an unknown number but many thousands of freight cars are absorbing sizable amounts of the new steels, even though relatively few new cars are pushing the matter to its logical conclusion.



First Standard Box Car Using High Tensile, Corrosion Resisting Steel Throughout Body and Underframe Built by Mt. Vernon Car Mfg. Co. 5410 lb. saved in weight of body

One might inquire whether strong steels may not be produced at a cheaper base price. Aside from the expectancy that prices will drop gradually with increased tonnage, the possibility of lower cost steels depends primarily on the use of less expensive alloying elements and

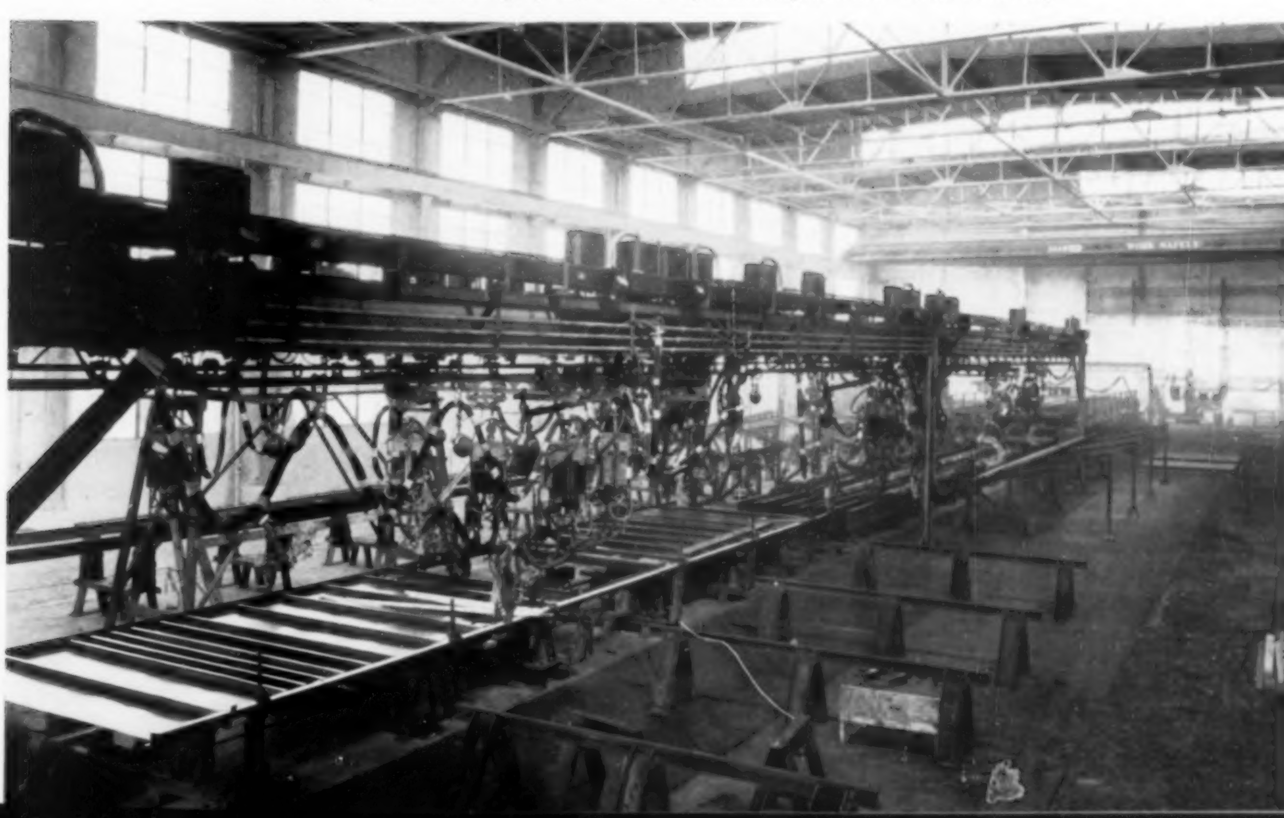
smaller percentages of them. Less expensive varieties of high strength steels would therefore depend on extra carbon, silicon and manganese (and sometimes copper) for a high yield point; such compositions are slightly air hardenable and are not as weldable as the lower carbon, higher alloyed steels. Likewise their corrosion resistance depends on their copper content and is no better than mild carbon steel with optimum copper (0.20%). Consequently these cheaper strong steels are more properly confined to car parts where welding is at a minimum, where they will be reasonably well protected from the elements, and where the required thicknesses for strength will give ample section for corrosion resistance.

Possibilities in Near Future

In view of the present reluctance (or impotence) of the railroad industry to plunge into a thorough-going program of weight saving, it is rather pointless to discuss ways and means of further refinement in design or of the use of more expensive metals of higher strength/weight ratios. For instance, the strain-gage tests on cars under collision at the higher speeds (up to 13.3 mi. per hr.) indicate that the center sill — the direct backbone of the car — takes the impact of buffing stresses, and the other members of the floor system are stressed 1/4 to 1/3 as much. Refinement to design against collision stresses would therefore involve added strength in the sill at the expense of other members. Of the other members the body bolsters are the critical parts. These and various parts of the truck could be made of heat treated alloy steel castings, although it is doubtful if much weight could be saved over a welded design using high strength steels. The body might be further refined by utilizing the aircraft monocoque or stressed skin construction, but this would involve much additional expense in getting and maintaining necessary flatness, nor would it add to resistance against impact. In this connection Wm. H. Mussey, research engineer of Pullman-Standard Car Mfg. Co., states that further weight savings are possible over the final design noted in the table on page 39 but at a considerable increase in cost. In one member alone a 400-lb. saving could be made but at a cost of $40, and this was judged to be too great a premium, just at present.

In the light of these facts, a guess might be hazarded as to the future trend. Railroad executives are generally conservative men — possibly an inseparable attribute to men of considerable responsibility — but it is no less true that they are competent and serious-minded. Any comparison of present-day equipment with that of 40 years ago will prove that there have been innumerable improvements adopted and larger and better equipment bought at advanced prices — once the industry can be convinced that the new equipment will pay its own way. Transition from wood cars to steel ones was not achieved over night; neither will the transition from carbon steel to alloy steel. The freight car of 1950 cannot help but be all welded of alloy steel; however, it will develop slowly, even piece-meal, with revisions and substitutions in each detail as its merits are proven.

Interior of New Freight-Car Shop, Pullman-Standard Car Mfg. Co., Arranged for Assembly of Car Bodies by Welding Rather Than Riveting



SAUVEUR MEDALIST

Candid camera shot by H. H. Harris

Harry Winchester McQuaid

Citation by the Committee of Past Presidents, American Society for Metals, on the selection of the man to receive the Albert Sauveur Achievement Award at the 1938 Convention: "In recognition of his pioneer studies upon the grain size and microscopic features of carburized steel, and particularly in recognition of the resulting stimulation of research upon grain size and hardenability of steel, the Albert Sauveur Award in 1938 is conferred upon Harry W. McQuaid."

IN PRESENTING Mr. McQuaid to the assembly for presentation of the Albert Sauveur Achievement Award for 1938, Edgar C. Bain, the senior past-president ⚙, used the following words:

Harry McQuaid can scarcely remember a time when, as a boy, he did not feel confident that he would be an engineer. At the age of ten years, he undertook an ambitious, though perhaps not quite perfect, survey of his father's farm near Englewood, N. J., where he later attended high school. Years later, at Stevens Institute of Technology, he learned that more mature engineers also had their difficulties with the error in closure of the traverse.

After receiving the bachelor's degree in mechanical engineering at Stevens Tech in 1913, he found himself taking care of the power plant at the United Piece Dye Works at Lodi, N. J., and soon after engaged himself with problems in the application of heat: "Soldering irons to soaking pits," McQuaid laconically explains this early activity.

In the autumn of 1915 he became night foreman of the heat treating department at Timken Roller Bearing Co. in Canton, Ohio, standing guard against the old enemies — soft spots and cracks — in casehardened parts. Here his experience widened as he was successively electrician on the electric furnace installation, and later helper. In 1918 he went to the metallurgical laboratory where much of his important work, mentioned in the citation for this Award, was done. Systematically following individual heats as to hardening characteristics and microstructure, he made the observations which resulted in his now familiar coarse and fine, normal and abnormal basis of classifying steel. From McQuaid's reminiscences of those days one learns that they were exciting ones, of well-filled hours under the inspiring leadership of the late Mark T. Lothrop, to whom he acknowledges a great indebtedness.

In 1920 Erik W. Ehn joined the laboratory staff and one may infer from McQuaid's account that the partnership of McQuaid and Ehn was happily one of mutually complementary abilities. By 1922 the concept of microscopic differences in slowly cooled carburized specimens, as between heats of inferior and heats of superior hardening capacity, was well matured and in use; accordingly a joint paper was read in February 1922 before the American Institute of Mining and Metallurgical Engineers, a patent application relating to the test having been made in 1921. The paper [reprinted substantially in full in this issue] drew forth considerable discussion and in a short time metallographists in all quarters were examining carburized specimens.

In 1926 Harry was transferred to the Timken-Detroit Axle Co. in Detroit, where he remained until 1933, when he joined the technical staff of Republic Steel Corp. as metallurgist. In 1935 he was chosen to deliver the tenth Campbell Memorial Lecture, and his subject was "The Importance of Aluminum Additions in Modern Commercial Steels". Other publications of his include a contribution to the 1934 Grain Size Symposium, a paper with O. W. McMullan on the selection of case hardening steels for highly stressed gears, as well as several articles in *Transactions*, METAL PROGRESS and other journals on case carburizing and the effect of aluminum in steel. He was active in establishing the single direct quench from the carburizing heat as a suitable practice for fine steels in high grade work, in introducing a generally higher hardness in automotive parts, and in the use of higher carbon in high speed steel cutting tools.

In the grain size work, for which he is perhaps best known, McQuaid collaborated with his steel producing neighbors in Canton and Massillon. While at first McQuaid and Ehn found a simple designation, "coarse" and "fine", adequate for grain size, later refinements were introduced. We understand that at United Alloy Steel Co. a ten-step series of standard grain size photomicrographs was prepared in 1924, while in 1926 a nine-step series with transition and core zones added appeared from Central Alloy Steel Co. At any rate, by 1928 the Timken series, now also the A.S.T.M. standard, of eight steps in a geometrical progression of grain sizes was prepared and is now in general use throughout the United States.

If anyone were to say that new ideas are immediately accepted in American metallurgical circles without critical discussion, he would be judged to be seriously ill-informed. Nor was this fascinating story of "structural normality" an exception. The basic central theme of the

story was confirmed by many investigators, while the significance and explanation of the observations became a subject of a plentiful amount of good, healthy, scientific controversy. Many of the brilliant researches prompted at least in part by the McQuaid publications were discussed before this Society, an example of the fostering of unhampered expression of view in which we may take pride. To mention only a few, the names of Brophy, Davenport and his Kearny associates, Epstein, Graham, Grossmann, Herty, Houdremont, Luerssen, Mehl, Nead, Rawdon, Scott, Shane, Sanders, and White come to mind. Who can say how much our present clear understanding of grain size and hardenability was hastened by the work of Harry McQuaid, or how far we should fall short of this status had McQuaid and Ehn not made their observations!

The Albert Sauveur Award is intended to reward those pioneer achievements, particularly, which have outstanding subsequent effect upon the thought and trends of study in the field. One might say, in short, that it is for those who really start something. We have seen McQuaid-Ehn tests employed by the tens of thousands and observed that masterful researches have been directed to the subjects revealed in his early contributions.

It is then an honor and a pleasure to present for the 1938 Albert Sauveur Award, Harry Winchester McQuaid.

Effect of Quality of Steel on Case Carburizing Results*

By H. W. McQuaid and E. W. Ehn

Metallurgists, Timken Roller Bearing Co., Canton, Ohio

IT IS USUALLY assumed that chemical specifications are sufficient for steel to be used for case carburizing, and if the steel analyzes within the ordinary limits specified for steel for this purpose, no difficulty traceable to the steel used should be encountered in obtaining satisfactory results in the case carburizing and hardening. Much work has been done to determine the effect of various alloying elements on the rate of carbon penetration, etc., but, to our knowledge, little if anything has been published in regard to the effect of the quality of the steel. . . .

It is the purpose of this paper to prove that the presence of excess dissolved oxides in the steel, as made in the melting furnace, affects permanently the results obtained in carburizing and hardening and that it is possible that the presence of dissolved oxide can result in total unfitness of low carbon steel for case hardening purposes. . . .

The case carburizing [of races and rollers for roller bearings] with which this paper deals was done in under-fired oil furnaces. The temperature of each furnace is controlled by means of a platinum thermocouple, in connection with a potentiometer indicator and potentiometer recorder. The temperature of each furnace is registered every 15 min. by an operator, who is continually checked by the automatic recorders.

The work prepared for carburizing is packed carefully [in bone-base compounds] in nickel-chrome carburizing pots of rather large size, 14x18x14 in. When loaded, one of these pots will weigh approximately 500 lb. Six of these pots constitute a furnace charge, making a total of 3000 lb. per charge. The time required to bring this charge to the carburizing temperature (1700° F.) varies from 9 to 10 hr., depending on the size of the pieces being carburized. [Time at temperature is about 24 hr.]. . . .

With each pot of work are packed pieces for check tests. These pieces when cold are taken from the pot, reheated to 1420 to 1440° F., quenched in water, broken, and the fracture examined. A 15% solution of nitric acid is used to develop the depth of case.

In spite, however, of the most careful inspection, trouble would occasionally develop in the hardening of case carburized material, and large quantities of material would be rejected after hardening because soft spots were found by the file. This, it was noted, occurred in particular lots of work when nearly 100% of the pieces showed soft spots in the hard inspection test. The pieces, it was also noted, could be traced almost exclusively to certain heats of steel made in basic openhearth furnaces. . . .

The carburized work, in the form of cups and cones for Timken bearings, is quenched in

*Reprinted from *Transactions*, A.I.M.E., (1922), Vol. 67, page 341.

special fixtures designed to produce the quickest possible chilling of the pieces — clear, clean water at 65 to 70° F. being forced against the surface of the raceway under a pressure of 50 psi. The pieces are heated in especially designed oil- or gas-fired furnaces of the rotating table type, the pieces being automatically carried through the heated zone to the outlet door, from which they are taken by the operator and quickly placed in the mechanically operated quenching apparatus. The process is so arranged that there is the minimum possibility of variation in the temperature of the pieces as they enter the quench. When it is found that a certain batch of work will not harden properly, special care is taken to insure proper quenching and work from batches known to be satisfactory is mixed, as a check, with the work giving trouble. If under these conditions the work from good batches hardens properly whereas the other work will not harden, it is accepted as proof that the cause of the soft work antedates the hardening operation. Great care is taken to check this conclusion. If when trouble of this character occurred the hardening temperature was raised considerably above the normal operating range (1420 to 1440° F.), little if any improvement would be found; although it was observed that the high temperature generally had little effect on the grain of the case, the usual coarseness of fractured case not being obtained with increased temperature.

Fig. 1 — Case of Normal Steel; 5% Picric Acid Etch. × 100

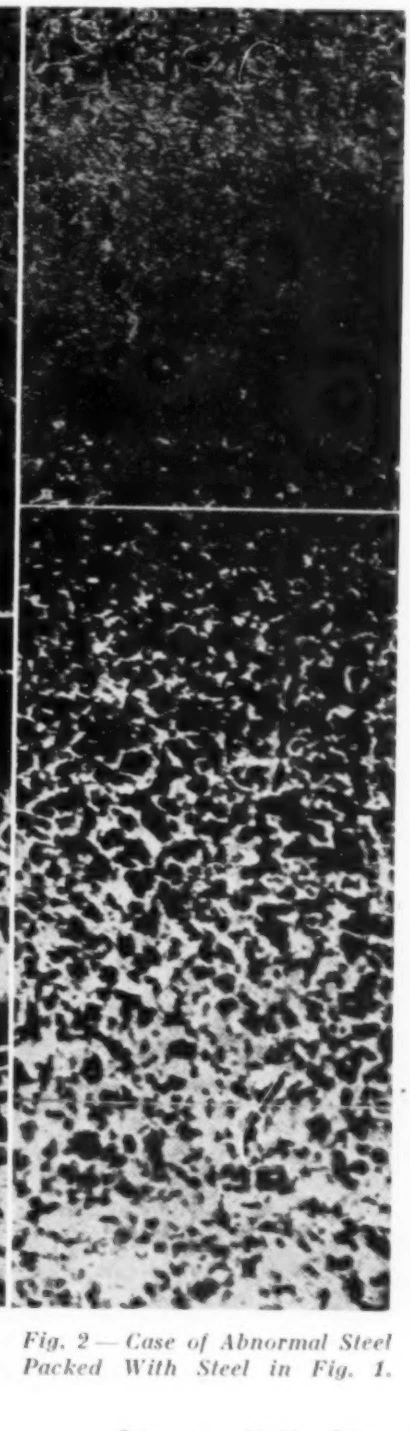


Fig. 2 — Case of Abnormal Steel Packed With Steel in Fig. 1.

When it was found that large quantities of certain sizes would not harden properly, the first step taken was to recarburize for a short time. This, in nearly every instance, failed to improve the result of the hardening. When it was found that the work that resisted all attempts to harden was confined to certain lots of basic openhearth steel, checks were instituted to determine the cause of the difficulty.

When work from these lots of basic openhearth steel was packed together (i.e. within ½ in.) in the same carburizing pot with the best grade of electric furnace steel and it was found that the electric furnace product gave excellent results in hardening, producing a deep martensite, whereas the openhearth steel products resisted all attempts to harden and the case was of variable martensite with a deep and variable troostitic zone, it was assumed that the cause of the difficulty must lie in some previous stage of manufacture and the carburizing department was eliminated as a factor. At this time representative compounds of the various types of carburizing agents were tried;

charcoal-barium carbonate, charred leather, and petroleum coke with added energizers all failed to improve results.

Samples were taken from forgings of basic openhearth steel from the same shipments as those giving trouble and from electric furnace steel and packed closely together in the same pot. It was found that the openhearth steel results were very unsatisfactory while the electric steel results were excellent. This check was then made on billets for the forging machines, bars from the rolling mills, blooms for the bar mill, and finally from the ingot. In all these cases the electric steel used gave satisfactory results while the basic openhearth steel produced very poor results, the hardened work being soft in spots and the fracture of poor appearance. After a number of such tests were made, it became evident that the cause of the hardening department troubles could not be in the working of the steel before carburizing, in the carburizing department, or in the hardening department....

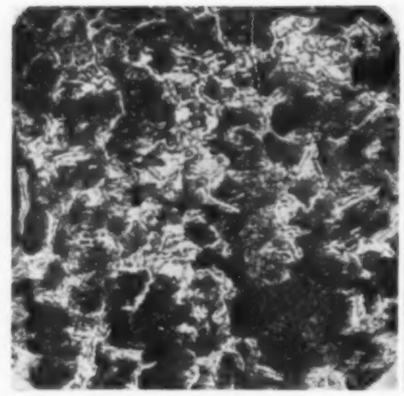


Fig. 4 — Section of Hyper-Eutectoid Zone in Abnormal Steel; Note Ridges of Heavy Cementite in Masses of Ferrite. Etched with 5% picric acid. × 200

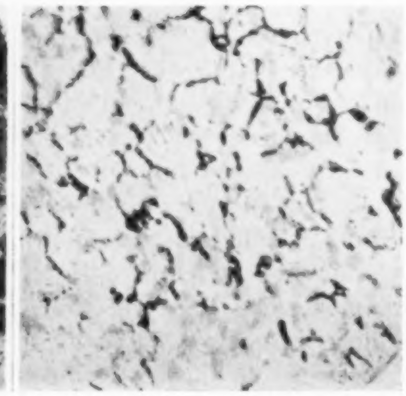


Fig. 5 — Section of Hyper-Eutectoid Zone in Abnormal Steel, Same as Shown in Fig. 4, Using Sodium Picrate Etch. × 200

Microscopically, it became a simple matter to detect steel after carburizing that would not form normal martensite after the quenching, the difference between it and the normal steels being easily distinguished by the experienced observer. [See Fig. 1 and 2 of case carburized and slowly cooled examples.] In the hyper-eutectoid zone of a normal steel.... the pearlite is very finely lamellar and the cementite exists as well-defined lines of fine but continuous formation at the crystal boundaries. Figure 4 represents the hyper-eutectoid zone of an abnormal steel. This steel was carburized under exactly the same conditions as [the normal steel], both specimens being packed close together in the same carburizing pot. In Fig. 4, the pearlite of the hyper-eutectoid zone has partly broken down to form massive cementite and free ferrite; the cementite can be distinguished as ridges having a white back ground of ferrite. Figure 5 shows the same specimen as Fig. 4 after etching with hot sodium picrate solution. Steel that, after carburizing, gives the results shown in Fig. 1 we have here designated as "normal"; steel that under the same conditions produces the results shown in Fig. 2 or 4 we have designated as "abnormal". [Figure 1 also shows] the gradation zone of normal steel, exhibiting the coarse crystal structure caused by the long exposure to the carburizing temperature (24 hr. at 1700° F.). [In the gradation zone of Fig. 2] the small crystal formation and the irregularity of this zone is characteristic....

Knowing that the breaking down of the normal pearlitic structure of the hyper-eutectoid zone was followed by soft spots after quenching, it became necessary to determine where the cause of this abnormal steel lay and to devise means for its elimination.

As stated, samples at various stages of conversion, from the ingot to the machined forging, were taken. It was found in most cases that the same condition existed at all stages of conversion and that with the steels used as a check the carburizing results were apparently unaffected by the condition of the steel, i.e., whether cast, rolled, or forged. After many tests covering a considerable time, it was decided that the cause of the unstable pearlite of the hyper-eutectoid zone after case carburizing existed previous to the ingot, i.e., it was in the steel furnace practice.

In this connection, it was found that the results to be obtained in carburizing and hardening varied with different heats of steel as made. This seemed to offer a means of checking and eliminating this class of steel as a steel of carburizing quality, as it only became necessary to carburize a section of a small test ingot poured from the ladle. This test was finally adopted after careful checking. It was found that if this small test ingot, poured from the middle of the heat, was unsatisfactory, apparently the whole heat was unsatisfactory....

Steel that shows indication of breaking down of the pearlite in the hyper-eutectoid zone after carburizing will harden successfully if this condition is not too far advanced, but the results obtained will not be as good as those shown by a really good steel. Abnormal steel will not respond as well to the quenching and it is difficult, if not impossible, to develop in hardening a satisfactory case. It is also true that the case obtained with abnormal steel will be of less depth than with normal steel, and will be more variable in character; [see Fig. 1 and 2]. In fact, most of the variation in carburizing results obtained when work is packed in a bone-base compound in the same carburizing pot can be ascribed to variation in the quality of the steel....

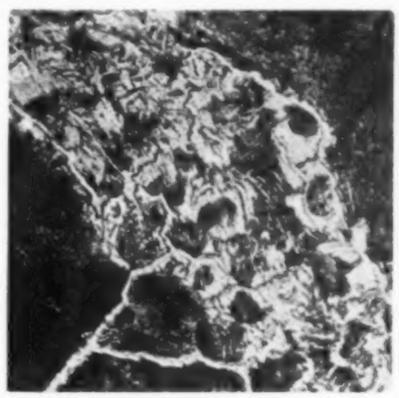


Fig. 27 — Ghost Line Through Hyper-Eutectoid Zone. × 100

In checking the carbon content and the gradation of the carbon from the surface to the core, test rings 2½ in. diameter by 1 in. face are made. Cuts are carefully taken from the surface in steps of 0.005 in. each. The sides are first cut away to a depth of 0.125 in. to prevent the carburized faces from affecting the check. The turnings from each 0.005-in. layer are separately analyzed for carbon content by the combustion method. Checking by this method shows the carbon content of the hyper-eutectoid zone of the abnormal steel to be the same as, or if anything, greater than, that of the corresponding zone of normal steel. Repeated analyses could determine no marked difference in the manganese, sulphur, or phosphorus content of the normal and abnormal steel.

A basic openhearth steel that contained a considerable number of heavy ghost lines was at hand; this steel offered positive evidence that a ghost line through the case would cause the pearlite to become very unstable and break down entirely in the hyper-eutectoid zone. This condition was checked many times, the hyper-eutectoid zone at all places being normal except at those spots where the ghost line persisted. [See Fig. 27.] As this was well established, it was necessary to determine what condition peculiar to the ghost line formation was interfering with the formation of normal pearlite.

In order to determine the effect of nonmetallic inclusions, the following test was made: Several holes $\frac{1}{32}$ in. in diameter were drilled in a section of electric furnace steel from a bar previously checked and found to be normal.... These drilled holes were filled with pulverized iron oxide, iron sulphide, and manganese sulphide and the holes closed by riveting. The piece was forged down to about ⅝ in. diameter and then reheated to 2200 to 2300° F. to fuse the oxide and sulphide, after which it was turned to ½ in. diameter and carburized for 24 hr. at 1700° F. The carburized rod was cut into sections and examined.... The results indicate simply that impurities dissolved in the steel tend to cause the disintegration of the pearlite. In the case of iron oxide, the carburization is almost entirely prevented, as could be expected.

As a further check, oxygen was blown onto molten electric furnace steel in a small ladle, by introducing a stream of oxygen from a commercial oxygen tank. Samples were machined, carburized, and the resultant case examined. The result, Fig. 32, shows the pearlite of the hyper-eutectoid zone to be almost completely broken down and the cementite entirely in the massive state. The steel, after being blown while molten with oxygen, proved to be absolutely worthless as far as case carburizing and hardening are concerned.

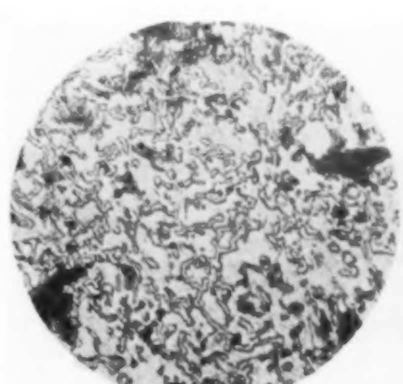


Fig. 32 — Hyper-Eutectoid Zone, Electric Steel Blown With Oxygen; Complete Pearlite Divorce. × 200

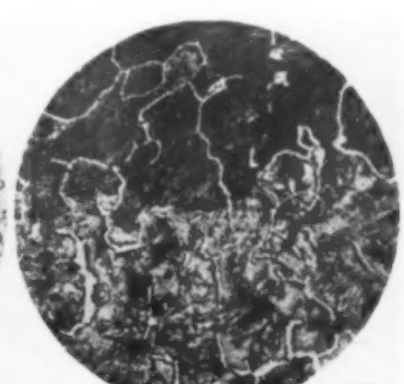


Fig. 33 — Carburized Weld; Abnormal and Normal Structure. × 200

Small pieces of normal electric furnace steel welded together by melting low carbon welding rod around them, in the oxy-acetylene flame, were carburized and examined. As shown, Fig. 33, the melted welding rod [below], subjected to a severe oxidizing action by melting, proved to be very abnormal whereas the electric furnace steel proved to be perfectly satisfactory....

It was also determined that a steel that would give a normal case after carburizing could be converted to an abnormal steel merely by heating to 2300° F. or over for from 1 to 2 hr. in an oxidizing atmosphere. This result, it is supposed, is due to burning and penetration of the oxygen into the steel....

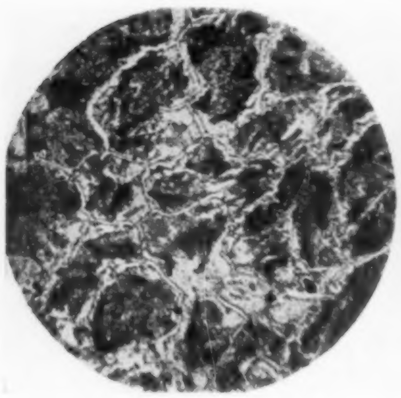


Fig. 39 — Hyper-Eutectoid Zone, Forged Electric Steel Ingot Poured Immediately After Melting Down Charge. × 100

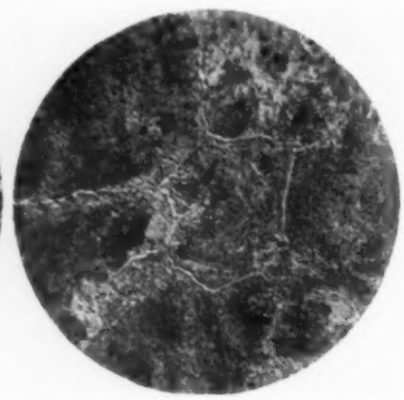


Fig. 40 — Second Stage of Same Heat: First Additions Made and Second Slag Shaping Up. Still shows pearlite divorce. × 100

It was also found that, in general, the steel produced in the 6-ton Heroult electric furnaces at the Timken plant, melting down cold scrap, reacted as abnormal steel until the ferrosilicon had been added, although some heats were much more abnormal than others. As the heat progressed the steel improved as far as the carburizing check was concerned, finally becoming normal after adding the deoxidizer. See Fig. 39 to 42. Some heats were found, however, that reacted normally just after melting down.

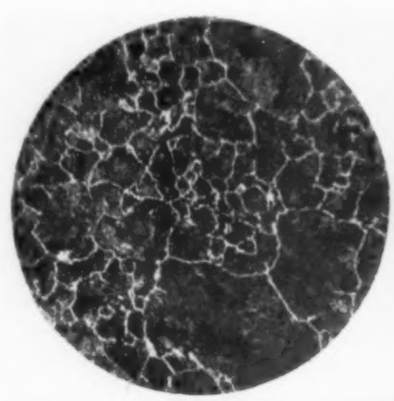


Fig. 41 — Third Stage of Same Heat as Specimen Shown in Fig. 39; Ferrosilicon Added; Nearly Normal. × 100

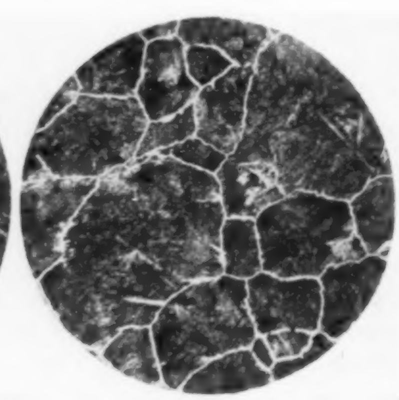


Fig. 42 — Finished Heat, Normal Steel

In order to check the results obtained by the writers, samples of steel with a statement of conditions under which they were obtained were submitted to Sauveur and Boylston for independent criticism. After investigating, they reported in effect that the evidence submitted indicated that the carburizing results were influenced by the condition of the steel as made and offered to submit, for check, samples of steel used by Mr. Boylston in connection with his work on the value of different deoxidizers. This was done, and it was found that the samples from the ingots deoxidized with ferromanganese, ferrosilicon, and ferro-carbo-titanium gave a normal hyper-eutectoid zone after carburizing, while the samples from ingots deoxidized with carbon-free ferrotitanium and aluminum gave an abnormal hyper-eutectoid zone, indicating a different condition of the steel....

Etching, by cupric reagents, of the free ferrite formed by the breaking down of the hyper-eutectoid zone of abnormal steel showed no indications of phosphorus concentration. It is believed by the writers that the carburizing (24 hr. at 925° C.) is sufficient to permit of the phosphorus diffusion, as all efforts to obtain evidence of segregated phosphorus after carburizing have failed, although the ghost lines still persist....

The effect of slag and silicates on the carburizing results has not been fully investigated, it being evident that these sonims could not be a principal cause. It was determined that in a 75-ton basic openhearth heat blooms from all sections of the heat were abnormal, indicating that the cause of the abnormal steel was present in all parts of the heat, a condition not likely to

be true if slag or silicates were a principal cause.

The investigations by Stead, Whiteley and McCance have indicated that dissolved oxide is one of the most probable causes of ghost lines. Le Chatelier and Bogitch have apparently proved that this is the case, which results are checked by the evidence obtained by the writers that ghost lines are the effect of the same cause as abnormal steel, namely dissolved oxides.

This is more or less substantiated by the facts that unfinished steel is, as a result, abnormal and that the addition of the deoxidizer (manganese, silicon, etc.) is necessary to produce normal low carbon steel. Why dissolved iron oxide should cause the divorce of the pearlite of the hyper-eutectoid zone is a subject for independent investigation; the most appealing explanation is that the solubility of the cementite in gamma iron is decreased by the presence of the dissolved oxide and hence it is more easily precipitated to the crystal boundaries on cooling through the critical range. The extent to which the cementite would be rejected to the crystal boundaries would depend on the amount of the oxides in solution as well as on the amount of the cementite and speed of cooling.

Brearly (Case Hardening of Steel, page 60) illustrates a condition identical with that met with in abnormal steels and ascribes the cause of the formation of massive cementite to low manganese content. Just how manganese is the cause of this condition is not explained but it is the writers' belief that the connection between the low manganese content and the divorcing of the pearlite of the hyper-eutectoid zone after carburizing is indirect, it being generally true that one result of a poorly deoxidized heat is loss of manganese content. It has been our experience that manganese content is an indication of the character of the steel, and that steel in which the manganese content is close to the minimum chemical specification is not as well made as steel in which the manganese content approaches the maximum specification for the element. This is true because manganese is added (as ferromanganese) to produce a predetermined percentage of that element in the finished heat, and when the finished content is less than that aimed at, it is assumed that the loss is due to the presence of oxides in the bath. It is possible that the loss in manganese may be compensated for by more complete deoxidation of the steel and hence the resulting steel might be of excellent quality. Unless otherwise noted, all steel carburized in connection with this investigation contained from 0.35 to 0.65% Mn.

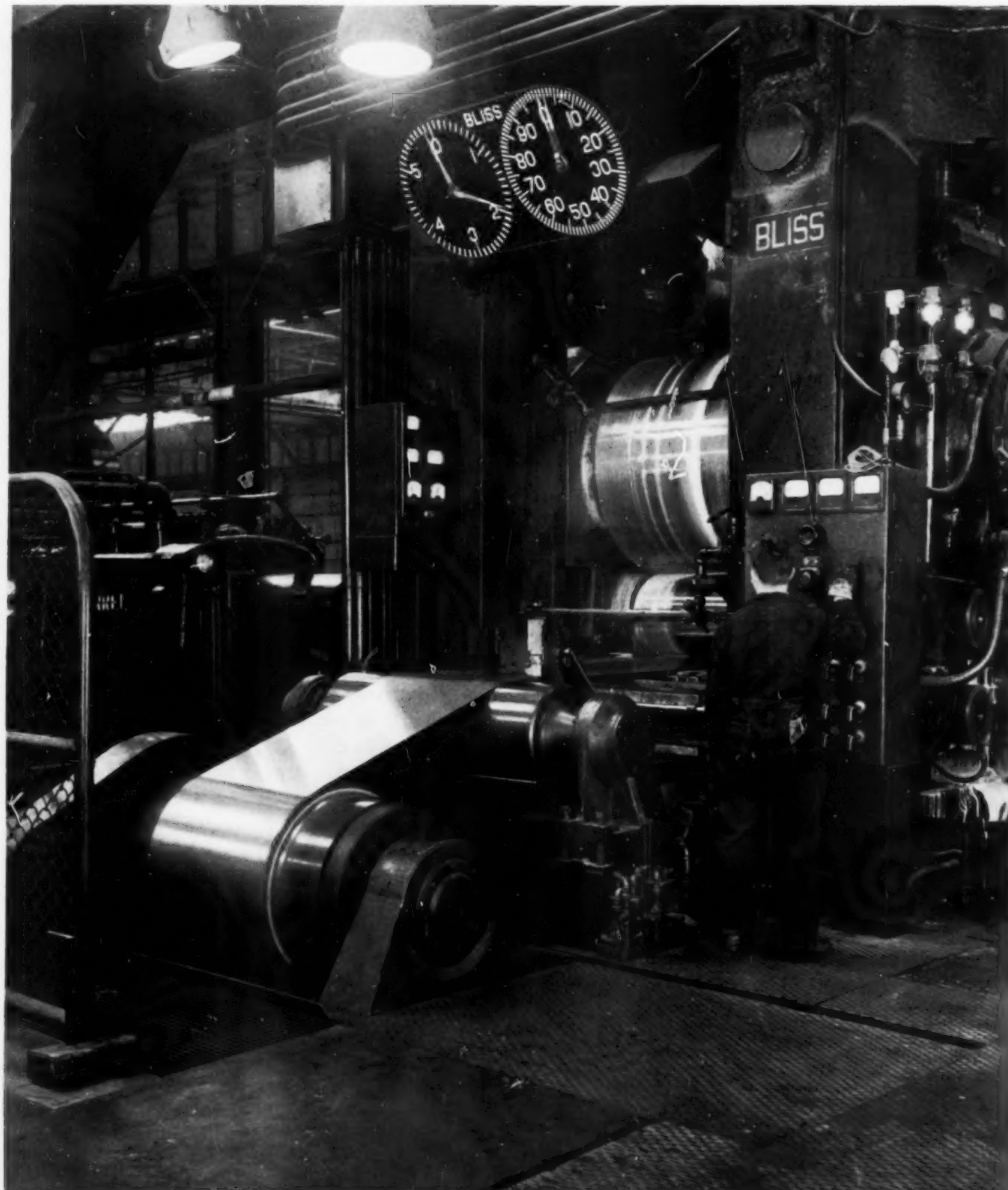
From the foregoing, it would seem that the extent to which deoxidation takes place in finishing steel in the melting furnace has an important bearing on results obtained after case carburizing and hardening; and, conversely, the results obtained in case carburizing constitute a check on the extent of deoxidation of the low carbon steel used for carburizing purposes; .... we have a method of inspection of this class of steel that will indicate under what conditions the steel was made.

While the writers have successfully adopted this method of checking steel for case carburizing, it has often been difficult to decide at just what indication of the divorcing of the pearlite to draw the line. There is not the slightest doubt that the structure of the case shown in Fig. 4 will not form normal martensite under the most favorable hardening conditions, but there is an intermediate stage between this and normal steel that will form martensite under proper hardening conditions but is more likely to develop soft troostitic areas than normal steel. ...

In order to check our method of inspection, samples from four heats of low carbon basic openhearth steel from one of the mills supplying us with openhearth steel were submitted for check, of which three were accepted and one rejected. It developed that the three accepted had been carefully made under the personal supervision of the openhearth superintendent, whereas the rejected heat had been deliberately picked out as poorly made. The success of this check resulted in obtaining the cooperation of the openhearth operating department and an improvement in the quality of the steel made for carburizing purposes.

On checking steel for case carburizing from another mill, it was admitted by the producer that the steel rejected was not originally intended for our use, but being within our chemical specification it had been diverted to our order. It was of "merchant bar" grade and showed up unusually poor when checked. It is not difficult to realize that the carburizing check is probably the only one that would have caused its rejection.

In conclusion, the writers desire to express their appreciation for the assistance and encouragement extended them by M. T. Lothrop, works manager of The Timken Roller Bearing Co., whose interest and direction has been of the greatest value.



A Reversing Sheet Mill

A piece of equipment in the recently opened Irvin Works of Carnegie-Illinois Steel Corp. at Clairton, Pa., with 4-high rolls 54 in. wide, driven by a 3500-hp. motor. Powerful reels at either side of the housing put tension into the emerging strip. A coil of hot-rolled and pickled sheet is drawn back and forth through these rolls at speeds up to 1000 ft. per min. until it has been reduced to required thickness for sheet or tinplate. All movements are under finger-tip control at the single point; thickness is automatically and continuously gaged.

RESISTANCE OF METAL

to stress and deformation

A report by
John S. Marsh
Associate Editor
Alloys of Iron Research
New York City

THE WEEK of the annual New York Meeting of the American Society of Mechanical Engineers brought its usual complement of bad weather. This, however, by no means dismayed the assembled engineers, because they frequented technical sessions and the Hot Spots with equal gusto. Since it is the former with which this report is concerned, it may be stated at once that many of those sessions contained items of interest to the metallurgist. The opener, from that point of view, was by M. L. Begeman, who offered a summarizing paper on "Hard-Surfacing Processes and Materials".

By "hard surfacing" Prof. Begeman meant those processes intended to increase the resistance to abrasion of wearing surfaces, whether by heat treatment (carburizing, nitriding, induction heating, flame hardening), metal spraying, metal plating, fusion overlays of hard materials, or by the incorporation of such materials as hard carbides. The paper was generally conceded to be a worthwhile review of the subject, although the metallurgists who were present seemed to agree that some items could stand alteration or amplification. Before turning to their remarks, a fact that emerged in the presentation of this paper recurred often enough to place it on the record once more: Mechanical engineers, on the whole, are still inclined to be naive about elementary metallurgy. (The manner in which the metallurgists acquitted themselves moves one to discount the potential countercharge. This may be playing ostrich, but....) A case in point, albeit unimportant, was the slides purporting to illustrate case-core combinations. These appeared to have been copied from coarse-screen halftones printed on pulp stock; to the flocked metallurgical birds they suggested everything from swarming bees to well-molded gorgonzola. Surely many an excellent photomicrograph could have been had for the asking. Another example, cited only to show the sort of thing that pops up unexpectedly, and certainly not to detract from the usefulness of the paper — which may be read, by the way, in the December issue of *Mechanical Engineering* — is contained in the following quotation: "Iron at temperatures close to and above its critical temperatures, that is 1550 to 1750° F., has an affinity for carbon. The carbon enters the metal to form a solid solution with iron; hence, the necessity for the high temperature." This, clearly, is the sort of thing designed to impel the metallurgical specialist to chew his nails back to the roots. Discussers were composed mostly of well-known ⊕ members; each injected or amplified his favorite theme. One topic deserving of special mention, however, was the nature of the bond between a sprayed-on coating and the stock. The only

unambiguous conclusion was that more is to be learned; uniform success in "hard surfacing" is by no means assured.

"Some Observations on the Yield Point of Low-Carbon Steel", by Joseph Winlock and Ralph W. E. Leiter, really started something. In fact, upper- and lower-yieldpoint phenomena raged off and on as a subject for several days, with a result perhaps indicated by A. V. de Forest's proposal to lock all contesting persons in a room for two weeks; he predicted that, at the end of such a period, each would be convinced of the validity of his own views and of the untenability of all others! A related paper, "The Effect of the Speed of Stretching and the Rate of Loading on the Yielding of Mild Steel", was presented by E. A. Davis. In keeping with Prof. de Forest's prediction, the authors of the two contributions found themselves at variance, with the discussers contributing to the confusion.

MECHANICAL Engineers, in annual meeting convened, spent much time discussing elastic and plastic action of metal under stress, ranging from phenomena of double yieldpoint of low carbon sheet steel, through a mathematical analysis of cold rolling action when the emerging sheet is under strong tension, to comprehensive studies of elasticity as applied to helical springs.

In brief, Winlock and Leiter held that the observed phenomena are characteristic of annealed mild steel, whereas Davis placed considerable emphasis on stress-concentration effects. Winlock and Leiter answered with several seemingly telling arguments, including the fact that even mild cold work obliterates the double-yield behavior. The audience seemed to become increasingly in favor of the plan for imprisonment of two weeks, but such drastic steps were side-tracked by Colonel Jenks's proposal that a committee for scientific study of the problem would be in order. This met with obvious approval, consequently the matter is likely to stay alive. Should one observer be correct in his statement that the upper-yieldpoint is indeterminate, and that the lower one is wholly a function of testing procedure, the committee will have a job on its hands.

The transition from problems of the steel-sheet user to those of the maker is not especially marked, consequently it is appropriate to report here that A. Nádai discussed "The Forces Required for Rolling Strip Under Tension". This preliminary report was not preprinted, and therefore rather difficult to follow, because of its high concentration of equations. However, the remarks of such eminent authorities as Messrs. Trinks and Stone indicated that Dr. Nádai has made substantial headway on the problem of mathematical analysis of rolling mill problems. This field too has its controversies and an associated rash of patent-itis — so much so, in point of fact, that a paper on "Tension Devices in Strip Rolling" was withdrawn before presentation. One point of immediately practical utility emerged from the discussion, namely that tricresyl phosphate as a lubricant in the rolling of steel sheet and strip combines the virtues of being a polar compound and of being non-corrosive. The audience also generously suggested several unsolved problems, such as the conditions conducive to the flattening of the rolls; Dr. Nádai also has work cut out for himself, for it appears that the experts in analytic mechanics are determined to conquer the rolling mill.

A glance at the program of a session on "Elasticity — Applied Problems and Mechanical Springs, I" hinted that the papers were not for the ordinary member of ⊕. This tentative conclusion was abandoned, however, upon observing a small stream of metallurgists entering the room. Perhaps the program annotations were misleading. An hour of it led to misgivings, removed only by a well-known ⊕ member who handles metallurgy and mechanics with equal facility. The observation that the drag of gravity on his eyelids was rapidly overcoming muscular counterthrust led to a solicitous inquiry, "Too much lunch?" He replied eloquently, "Hell no! Too much mathematics." Otherwise, the conclusion was reaffirmed that to many engineers and physicists, steel is steel.

The second session was different. In slides illustrating "Deflection of Helical Springs under Transverse Loadings" by W. E. Burdick, F. S. Chaplin, and W. L. Sheppard, actual springs of the kind used in railway trucks were shown under test. After that, formulas for computing such quantities as the transverse deflection of a

helical spring under vertical loading did not seem so formidable. Similarly, C. T. Edgerton's "Research Report on Helical Springs" hit a peak of metallurgical interest. This report reviewed fatigue tests of full-size helical springs at Wright Field. Materials consisted of acid openhearth, basic openhearth, and electric carbon steels. No significant differences appeared, provided that the steels were well made. Of considerable interest was Mr. Edgerton's method of plotting the data; instead of familiar *S-N* diagrams consisting of two intersecting straight lines, rectangular hyperbolas were shown. Endurance limits were indicated by the asymptotes parallel to the number-of-cycles axis. In response to objection from members of the two-straight-line school, Mr. Edgerton revealed his hole card: The hyperbola plotted semi-logarithmically is astonishingly close to the straight-line arrangement. There is some doubt about whether the exponent 1 (required in the formula for the rectangular hyperbola) provides a curve which best fits the plotted data, and it is not wholly certain that the *S-N* relationship is really hyperbolic, but there is no doubt that the interesting and promising possibility deserves careful examination.

One other activity of the Special Research Committee on Mechanical Springs should be mentioned. A progress report on a book by D. J. McAdam, Jr. and R. W. Clyne on "Strength of Metals with Special Reference to Spring Materials", sponsored by the committee, was read by Dr. McAdam. Publication in 1939 was promised. This book will contain a wealth of material of interest to metallurgists.

Owing to the impossibility of occupying two points in a Newtonian coordinate system at a given instant, several of the papers must be recorded more or less by title. In "High-temperature Steam Experience at Detroit", R. M. VanDuzer, Jr. and Arthur McCutchan quoted results of creep and corrosion measurements on alloy steels in turbines. "An examination of all principal materials used in the construction of the turbine, piping, and superheater showed that with several exceptions the alloys were in good condition. Measurements made to determine creep disclosed only small amounts." Further: "The results of 1100° F. steam-corrosion tests indicate that the scale formations offer material protection against subsequent steam attack. . . ."

"Changes in a High-Pressure Drum to Eliminate Recurrence of Cracks Due to Corrosion Fatigue" were described by A. E. White. Failures were attributed to corrosion fatigue resulting from stresses caused by temperature changes together with contact with water of relatively low pH value. Changed design is believed to have overcome the trouble.

Then, for the machine-shop folk, there was "The Effect of Size and Shape of Cut Upon the Performance of Cutting Fluids When Turning S.A.E. 3140 Steel", by O. W. Boston, W. W. Gilbert, and L. V. Colwell. Judging by extant volumes of the *Transactions* of this society, this subject is not quite beyond the pale; however, brief attendance during the discussion period unearthed a strong tendency merely to swap yarns about machinists' legends.

The last paper of metallurgical interest was really a metallurgical detective story told by G. F. Jenks: "The Interpretation of a Failure of an Ordnance Structure" (or, less euphemistically, why a gun blew up). Colonel Jenks pursued the results of macroscopic and microscopic examination and of mechanical tests to a most logical conclusion, then stated that: "One last check completes the story. The manufacturing records were consulted and disclosed that the area in question had been welded by metallic arc to correct an error made in machining." The assembly questioned not a single point in the analysis, for the simple reason that it was irrefutable. Rather they were moved to admiration for the irresistible explanation of the failure, and proposed that it would be a real service to teach such methods of analysis in academic circles. The professors demurred on the ground that callow youth is not interested, and suggested an "age coefficient" for the human equation. (Student papers please copy.)

Anyway, it was an interesting end to the proceedings, unless a statement about the photographic exhibit would make a better coda. To stick out the week, *(a)* exhibits were pictorially and technically superior to those of 1937; *(b)* low-hung suns over moody seas were plentiful (surely the M.E.'s can see *something* in other subjects); *(c)* the favorite paper seemed to be velour black.

Note to the Editor: With your past justifiable complaints in mind, it is a pleasure to report that room temperatures were agreeable, and that the smoke concentration was well below the eye-sting threshold value. Perhaps the power of the pen *is* . . . and so on and so forth.

VALVES AND VALVE SEATS FOR GAS ENGINES

By F. R. Banks

Abstract from Journal, Institution of Automobile Engineers, December, 1938, p. 32

ASIDE from numerous mechanical and design requisites for exhaust mechanisms, the valve material should have high strength at elevated temperatures; it should be resistant to scaling and to hot and cold corrosion attack. A certain degree of stem hardness and wear resistance is necessary. It should also have good heat conductivity.

The designer of the automobile engine is at some disadvantage to his brother, the aero-engine designer; the former is much limited in manufacturing costs, but the latter seeks performance and reliability regardless of money considerations. The size of the automobile engine imposes further restrictions in design elaborations, so the aero-engine exhaust valve costs from 50 to 200 times that of the automobile exhaust valve.

The valve material most commonly employed in English and American automobiles is silicon-chromium steel, more commonly known as "Silcrome No. 1". Its general composition is given in the table. It has proved itself to be a very satisfactory steel, but careful control and good inspection are necessary in the manufacture. Valve failures still occur; many are due to faulty control in the electrical upsetting and the final stamping methods employed by some of the quantity production plants.

Two new steels have been recently introduced in America, Silcrome "XCR" and a slightly cheaper one, "XB". The latter is replacing Silcrome No. 1 in the United States. "XCR" receives mainly only one heat treatment, which consists of a 14-hr. draw at 1400° F.; this produces a good hardness for seat and stem. The temperature range for forging is very narrow, between 1975 and 2000° F. It is reported that this steel when properly controlled and handled, is superior to all others, excepting the stellited variety. Valves from "XB" are used in a normalized condition with only the tip hardened; it has superior resistance to oxidation and corrosion and better hot strength than Silcrome, and its coefficient of expansion is similar.

The austenitic steel commonly used in British aircraft valves is D.T.D. 49-b. It is not used much for automobile engines, but with stellited seats is satisfactory for heavy duty. Austenitic steels such as this have a high hot strength and are very resistant to oxidation and hot and cold corrosion. Their coefficient of expansion is somewhat high, and they have a tendency to pick up in the valve guide. Their thermal conductivity is lower than Silcrome steel and they tend to run hotter. Use of hollow valve-stems containing sodium to conduct the heat back into the guide is therefore essential for an aero engine, but impracticable even on truck engines unless large diameter stems can be used.

It is necessary to weld a hardenable tip on austenitic valves. Stellite is favored in England, but hardened 1.10% carbon toolsteel (or S.A.E. 3140 for cheap jobs) is used in America.

American aero-engine exhaust valves represent the highest state of poppet valve development. Practically all large American engines are radial air-cooled, with two valves per cylinder. The exhaust valve of such an engine is about 3 in. diameter and weighs about 1 lb. *(Continued on page 84)*

Steels Commonly Used for Exhaust Valves

	Silcrome No. 1 *(a, b)*	Silcrome XCR *(a)*	Silcrome XB *(a)*	Thompson Products Alloy *(a)*	D.T.D. 49-b *(b)*
Carbon	0.40 to 0.50	0.40 to 0.50	0.60 to 0.86	0.40 to 0.50	0.35 to 0.45
Silicon	3.50 to 4.25	1.0 max.	1.25 to 2.75	0.30 to 0.80	1.0 to 1.75
Manganese	0.40 to 0.60	1.0 max.	0.20 to 0.60	0.70 max.	0.50 to 1.0
Sulphur	0.03 max.	0.035 max.	......	0.025 max.	0.03 max.
Phosphorus	0.03 max.	0.035 max.	......	0.030 max.	0.03 max.
Chromium	7.5 to 8.5	23.2 to 24.2	19 to 23	13 to 15	12.5 to 14.5
Nickel	0.50 *(c)*	4.5 to 5.0	1 to 2	13 to 15	12.5 to 14.5
Molybdenum	....	2.5 to 3.0	......	0.50	....
Tungsten	....	....	......	1.75 to 3.0	2.0 to 3.0
Hardness	Brinell 255 to 286	Rockwell C-42 to 44 / Scleroscope 50 to 57 *(d)*	Scleroscope 55 to 60 *(e)*	*(f)*	*(f)*

(a) Used in Great Britain. *(b)* Used in America. *(c)* Usually absent in American varieties. *(d)* After 14 hr. anneal at 1400° F. *(e)* Usually used in normalized condition with tip hardened to figures shown. *(f)* Austenitic steel; requires welded-on tip of hardenable steel.

WELDABILITY OF STEEL

requires low oxygen content

By C. A. Liedholm
Metallurgical Engineer
Jessop Steel Co.
Washington, Pa.

NECESSITY for meeting unusual and difficult specifications may in fortunate cases lead to quite unexpected findings. The production in quantity of large welded objects of S.A.E. 6130 analysis (Cr 1.0%, V 0.18%) to the most rigid physical requirements — involving final inspection by wet magnaflux as well as extreme accuracy of dimension — created a demand for steel able to meet an unusual quality test for "weldability" developed by J. H. McKee of Pittsburgh Screw & Bolt Corp.

This test consists simply in studying the steel during fusion while melting a bead across the surface of the material to be tested with the atomic hydrogen torch. The weldability of the metal is rated by a responsible operator on a percentage basis, 70% being considered the minimum satisfactory rating, while 80% is considered excellent.

In rating the weldability, the following rules serve as a guide:

1. Continuous as well as intermittent gas evolution from the metal during fusion is particularly undesirable in the production of high grade welds, since both types are prone to lead to porosities; a slight agitation from within the molten metal is permissible as long as it does not interfere with the arc or welding flame, or lead to the formation of pits or craters in the resulting bead.

2. The occasional ejection of sparks — usually one or two at a time — is objectionable if it causes interruptions in the welding arc.

3. Undercutting along the edges of the finished bead is undesirable, since a sharp demarcation between weld and steel is a stress-raiser which may initiate fatigue failure of the finished part.

4. Good fluidity is considered a favorable factor, poor fluidity an unfavorable factor in the final rating.

Accompanying figures show the results of such weld rating tests of some experimental heats of widely varying weldability. Data about these heats will be given later.

Prior to the evolution of this test, the manufacturer's statistical data covering a period of several years had shown that an abnormal number of rejections for unsound fusion zones, as well as for hairline cracks in the heat disturbed zone, usually were confined to certain heats. After the test had been made a condition for acceptance, such rejections of welded parts were practically eliminated.

The value of the test being established, it remained for the steel maker to determine the factors which might influence the weldability rating in order to consistently produce acceptable material. The purpose of this article is mainly to outline the findings of the investigation and to point out some important factors discovered.

To begin with, it was found a different matter indeed to produce a steel of satisfactory weldability rating, and merely to make a steel with sound macrostructure, annealed to a certain hardness, and developing a specified set of tensile properties upon prescribed heat treatment. Structure after hot etching, microscopic cleanliness, microstructure, hardness, and physicals, would usually appear just as satisfactory whether the weld rating was high or low. A series of McQuaid-Ehn tests revealed no consistent differences between fine-grained and coarse-grained, or normal and abnormal steels, as far as weldability is concerned. A detailed study of the melt logs of all heats whose weldability rating was known, proved an equally fruitless undertaking.

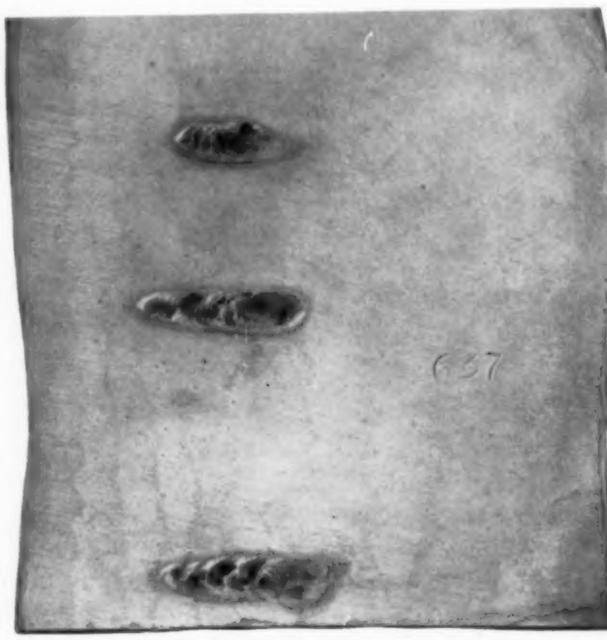
Factors such as surface finish — whether pickled or sandblasted — stresses from the straightening or shearing operations, rolling temperatures, and even variations in all the single elements of the analysis within specified limits, were investigated and gradually discounted as having no bearing on the welding properties.

Small pilot heats were next prepared in an induction furnace for preliminary investigation of various single or complex factors such as scrap contamination and variations in the deoxidation technique. Though of no importance to the final satisfactory solution of the problem, the observation may be of interest that the presence of titanium in even comparatively small quantities appears to have an adverse influence, as shown by the following parallel test melts:

Source of Scrap	Melt No.	Weldability	Ti added
Heat No. 8841	11	80%	None
	12	65	0.025%
	13	65	0.05
	14	60	0.10
	15	60	0.15
Heat No. 8840	16	80%	None
	17	70	0.025%
	18	60	0.05
	19	70—	0.10
	20	70	0.15

In such experiments as these different scrap was used for each series, but the melts of each group (11 to 15, and 16 to 20 inclusive in the above table) were all melted from the same scrap (Heat 8841 and Heat 8840 respectively). A warming-up heat preceded each test run, and all melts were accorded the same time — about 15 min. — between the beginning of melt-down and tap. At no time was the tester informed about the history of the steel he was testing.

Since the observation on titanium was interpreted as pointing to scrap contamination as a possible cause of differences in weldability, a number of heats of various ratings were selected for spectrographic analyses. The customary chemical analyses are shown in the table opposite (sulphur and phosphorus in all instances



Heat 637 With Weld Rating of Zero

Heat 639 With Weld Rating of 20

are below 0.020%). The consultant spectroscopist reported identical figures for all these heats in the first group in nickel (0.01 to 0.1%), copper (0.1%), molybdenum (0.01%), calcium (0.01%) and zinc (0.001 to 0.01%). Cobalt and tin were each reported on the order of 0.001 to 0.01% for Heats 636, 9528 and 9719 and 0.01% for the rest; lead was reported on the order of 0.001% in all except 638 which was 0.001 to 0.01%.

Chemical Analyses of Raw Materials

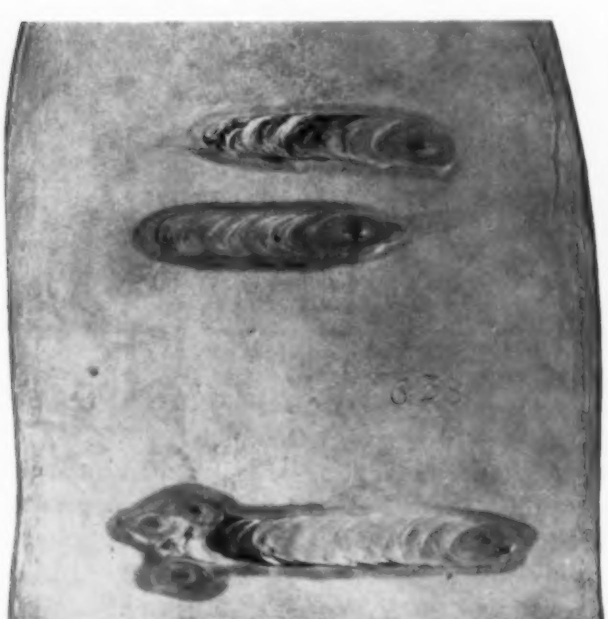
Heat	Weld Rating	Carbon	Manganese	Silicon	Chromium	Vanadium	Titanium
			First Group				
636	75 to 80	0.29	0.59	0.35	0.89	0.20	Nil
637	0	0.30	0.71	0.40	0.83	0.22	0.30
638	60	0.37	0.64	0.37	0.93	0.30	Nil
639	20	0.46	0.72	0.48	1.02	0.28	Nil
9520	80	0.29	0.70	0.38	0.93	0.21	Nil
9528	65	0.305	0.72	0.43	0.89	0.21	Nil
9719	85	0.35	0.71	0.32	0.87	0.20	Nil
			Second Group				
7741	80	0.30	0.64	0.41	0.96	0.20	
8471	50	0.28	0.54	0.31	0.89	0.20	

Magnesium was on the order of 0.001% in Heats 637 and 639 (low weldability ratings), 0.001 to 0.01 in Heats 636, 638 and 9520 (ratings 60 to 80%) and on the order of 0.01% in Heats 9528 and 9719 (ratings 65 and 85% respectively). Aluminum was reported on the order of 0.001% in Heat 636 (rating 75 to 80%), 0.001 to 0.01% in Heat 638 (rating 60%), on the order of 0.01 in Heats 9528 and 9719 (ratings 65 and 85%), and on the order of 0.01 to 0.1 in Heats 637, 639 and 9520 (ratings zero, 20 and 80% respectively).

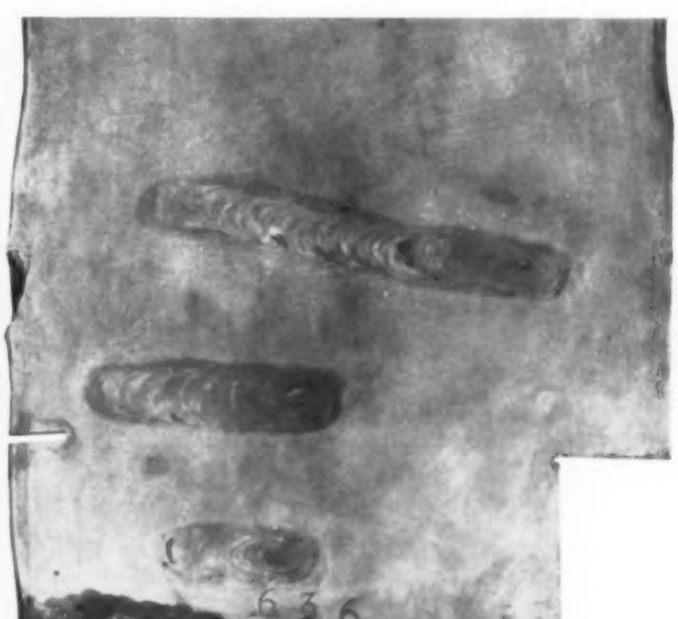
Obviously, the spectrographic analyses justified the omission, at least tentatively, of scrap contamination from further consideration as a major influence on welding qualities.

A different story was told by the results of vacuum-fusion analysis for determination of oxygen. Specimens of the second group (of 80% and 50% weldability rating) were analyzed for oxygen by two investigators, one of whom reported fractional values. The discrepancy between their figures was quite large, but the relative difference between the oxygen contents of the two steels was in good agreement. Following a lead suggested by these findings a period of no rejections followed at the steel mill, but about 18 months later there was a recurrence of trouble, occasioning further investigations. In addition to a review of the spectrographic analyses, a set of five samples from the first group were submitted for vacuum-fusion analysis to one of the two previous investigators.

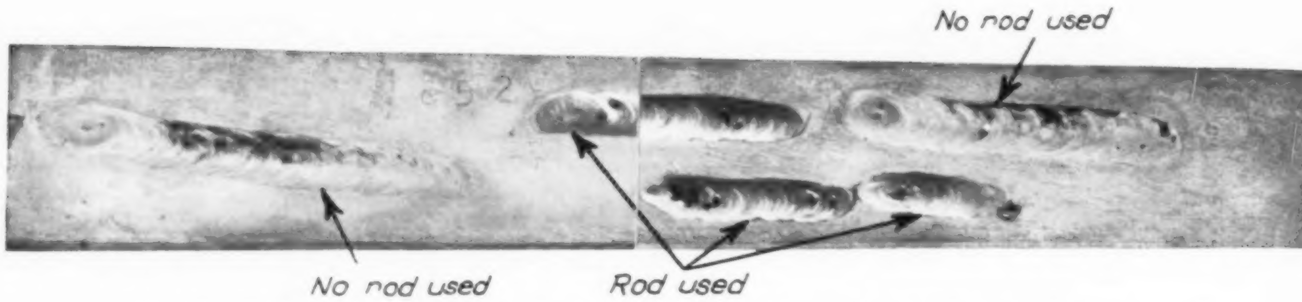
With due consideration for the factors of



Heat 638 With Weld Rating of 60



Heat 636 With Weld Rating of 75 to 80



Heat 9528 With Weld Rating of 65. Note that in testing this heat, rod was added to some of the beads. This practice is used in doubtful cases; here, the addition of the rod material intensified the previously slight cratering, and the heat therefore was rejected

uncertainty and experimental error inherent to the vacuum-fusion method, and making allowance for possible constant differences between different experimental runs, as well as for the fact that the weld rating test is purely a matter of personal experience and judgment without any strictly scientific basis, the relative consistency between the oxygen content of the steel and its weldability is good, and points to a definite interdependence of these two determinations.

This opinion was considered sufficiently well founded to intensify previous efforts to solve the problems involved by a gradual, complete revision of the melting practice. Some points ultimately considered of established importance in this respect were the selection of clean, not excessively fine scrap, and careful control of the oxidation during melt-down. The finishing period was featured by slag control and special deoxidation practice. Data not ordinarily recorded on the melt log were carefully noted and considered in relation to the results obtained. Extreme vigilance was found a paramount requirement, even a minor lapse in the observance of desirable precautions having been found to depress the weldability rating. Results of this work have to date been gratifying, showing the production of about 97% satisfactory heats with about 80% average weldability of all those made over an extended period.

While the stated conclusions have not been reached by a strictly scientific investigation, they may be considered well substantiated by the practical results. Although a single type of material, S.A.E. 6130 was studied, and only the atomic hydrogen welding process was involved, the findings may well have a much more general application. While hitherto considered factors such as hardenability undoubtedly impose limits on the weldability of steels, it is believed, on the basis of the reported experience, that the possibilities of a particular analysis can be fully realized — as far as welding is concerned — only when the material has adequately low oxygen content. This belief is further borne out by the attainment of just as good welds with otherwise identical analyses of the 6100 series when the carbon was as high as 0.38% (on experimental melts), as when it lay in the vicinity of 0.20%. Variations within the specified limits of the 6130 analysis (conventional elements) have been found entirely without influence upon the quality of the welds of the finished articles, as long as the steel showed a satisfactory weldability rating.

Non-Fractional Gas Analyses by Analyst "B"

Heat	Rating	Oxygen	Nitrogen
	First Group		
636	75 to 80	0.0040	0.0109
637	20	0.0076	0.0028
9520	85	0.0048	0.0086
9528	65	0.0055	0.0085
528	85	0.0023	0.0013
	Second Group		
7741	80	0.0061	0.0126
8741	50	0.0085	0.0170

Fractional Gas Analyses by Analyst "A"

	Heat 7741	Heat 8471
Weld rating	80%	50%
1150° C. (oxygen as FeO and MnO)	0.0019	0.0043
1350° C. (oxygen as SiO_2)	0.0038	0.0087
1550° C. (oxygen as Al_2O_3)	0.0083	0.0068
Total nitrogen	0.0150	0.0148
Total hydrogen	0.0002	0.0007
Total oxygen	0.0140	0.0198

PITTING OF GEAR TEETH

in large cast steel gears

By James L. Avis
Consulting Metallurgical Engineer
Seattle, Wash

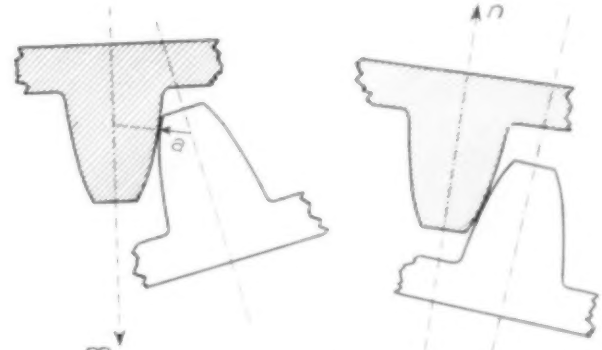
IT WOULD SEEM to be the general impression among manufacturers and users of gears that the pitting often observed is due to some type of corrosion. It is seldom we find pitting in small gears of forged alloy steels if they have been correctly designed and heat treated, and operated under good conditions of lubrication. This short article does not relate to the latter, but is concerned with those gears ranging from 3 to 6 ft. in diameter, such as are frequently cast in electric steel foundries.

One such casting was recently studied by the writer. It was a 5-ft. diameter herringbone gear, with teeth faces approximately 5 in. wide and of the size and profile shown by the drawing below. Along both faces of the teeth in this gear were pits — round, oval, irregular, and in streaks. Some manufacturers call this a case of spalling or scuffing, and yet there is all the appearance of quite pronounced corrosion pitting. This particular investigation disclosed a very different condition.

Referring to the drawing, the left sketch represents a tooth of the driver gear (cross-hatched) entering the driven gear. From the point *a* where contact is first made, the movement is in the direction *m* until the pitch circles of both gears are tangent. When this occurs the relative movement is reversed, as is shown in the right hand sketch. Such movements are accompanied with considerable pressure and friction.

Ductile steels lend themselves very readily to plastic deformation of an extensive nature; even fairly hard steels do this to a surprising degree when sufficiently stressed — witness the peening or mushrooming effect of the hammered end of a drill or chisel. What is meant by the term "plastic deformation" and what are the effects?

Since all metals are crystalline in structure, the reactions to load are difficult to analyze. However, if a stress is applied of sufficient intensity to approach the elastic limit but not



Sketch Showing Alternation in Direction of Sliding Friction (and Resultant Stress) as a Pair of Gear Teeth Progress From First Engagement to Final Clearance

Photograph at 50 Diameters of Unetched Surface of a Gear Tooth, Showing "Streak" to Be a Channel Through Cracked Surface Metal, Partly Filled With Metal Fragments

exceed it, minor movements within the crystals take place. Remove the stress and all elements return to their former position. This is the definition of elastic action.

If, however, the applied stress reaches or exceeds the elastic limit more pronounced movement occurs; the crystals shear and some blocks move past the others to new positions; thus deformation becomes permanent, even after all stress is removed. With repetitions of this intense stress, particularly as applied by two meshing teeth as in this case, a surface flow of metal takes place which is termed plastic deformation. Plastic deformation is accompanied by strain hardening; when pushed too far the crystalline bonds are actually ruptured by the over-work.

TEETH on large cast steel gears sometimes become pitted and grooved within the rubbing areas in a manner strongly suggestive of corrosion. A closer examination indicates the trouble to be fragmentation of heavily cold-worked metal in small areas where stress is concentrated beyond the ability of the metal to resist.

Severe plastic deformation therefore leads to eventual failure — and with special ease if the stresses causing it first push in one direction and next pull in another direction. This is the action in some gears, for, as shown in the sketch, when the tooth of the driver gear enters the stress is in one direction and when leaving the stress is reversed. Such reversal of stress, if sufficient to produce pronounced crystal deformation and if having many repetitions, is the explanation of the cause of most fatigue failures. It is also possible, of course, to produce fatigue failures where the maximum stress, sufficient to cause pronounced crystal movement, is only in one direction (as when the load is alternately applied and released).

When newly cut gears are put to work, their contours do not in all instances truly mesh throughout their entire tooth-length. Many causes might be cited, such as slight inaccuracies in machining, warpage or stress relief within the casting, minor misalignment of the bearings. Examination after a definite service period then discloses that not all of each length of tooth had been in intimate contact, and in these teeth the stress was confined to small areas. With plastic deformation or flow of the surface crystals at such areas, released or even reversed on each revolution, localized fatigue failures occur and the embrittled, disintegrated and highly comminuted crystals drop out or are partly entrapped by the lubricant, causing an appearance strikingly analogous to well developed corrosion pits.

Also there are instances where, after "running in" and sufficient time has elapsed whereby the teeth mesh accurately and take bearing throughout their entire length, and sufficient area is in contact to distribute the loading evenly to the condition where localized stresses are eliminated and the average stress is considerably below the elastic limit — no plastic deformation then occurring — examination has disclosed that the pits have disappeared.

The first photomicrograph is an external view along one of the streaks in a tooth face. There is a rough channel in the surface about 0.015 in. wide containing disintegrated crystals entrapped by the lubricant. Alongside this area are to be seen fine hair cracks, showing that the distorted surface metal is in an advanced stage toward breaking up.

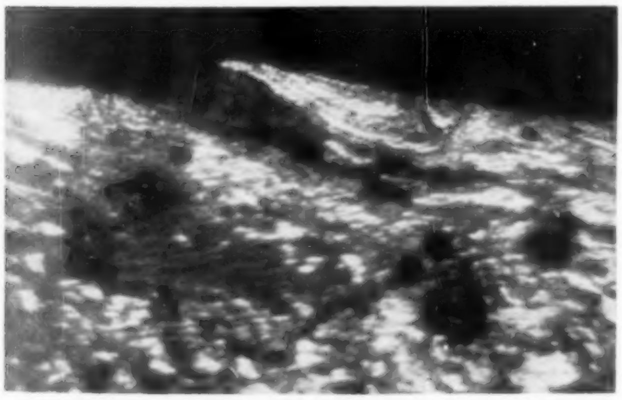
That the surface has been greatly distorted

and sometimes spread out in a tapering film is shown by the second photo, a profile, macro-etched to show the greatly elongated ferrite crystals of much the same appearance as we find in longitudinal sections of cold-drawn wire. Sometimes entrapped comminuted metal is disclosed within the dark irregular lines representing the fissures.

The general microstructure of the annealed casting as put into service is normal. It contains occasional small inclusions, appearing as they always do surrounded by ferrite or in the ferrite crystals. There is the possibility these could form the nuclei for electrolysis, but there is no evidence of this in the sample which has furnished the material for this article.

It is rather doubtful if this steel would exceed 45,000 psi. for the elastic limit, as the carbon content is low and it contains but a fractional per cent of chromium. Evidently, to improve this condition of "pitting" it is necessary to produce a steel that will be sufficiently high in elastic limit to prevent (or at least limit) plastic deformation. While this may be done by quenching and tempering, most of the small foundries have no real heat treating equipment; they are forced to rely on either normalizing or full annealing. The solution of their problem would then be to pour heats of approximately 0.45% carbon to which an addition of perhaps 0.50% molybdenum is made, and anneal the resulting castings.

While this is not offered as a deeply scientific research problem, the writer has the idea that it might be of some help to some exasperated user of large cast gears or some befuddled foundryman with limited equipment for experimentation.



Tooth Profile, Etched at 200 Diameters, Showing Heavily Cold-Worked Surface Metal (Similar in Structure to That of Cold-Drawn Wire) Worked Out Into a Sliver Over a Surface Crack

SINTERING

of hard carbides & nitrides

By Oskar Meyer and Walter Eilender

Abstracted by W. D. Jones (in The Metallurgist, *Oct. 28, 1938, p. 171) from article in* Archiv für das Eisenhüttenwesen, *1938, p. 545*

AFTER reviewing the present status of the art, the preparation of sintered tungsten carbide (WC) with cobalt binder is described in detail. To prepare the carbide pure tungsten powder (particle size 5 to 7 microns) is mixed with glucose and lampblack, ball-milled, dried, and heated 1 hr. at 1600° C. in a vacuum tube furnace, crushed, reground and the heating cycle repeated. Cobalt powder is reduced from oxalate in hydrogen. Mixtures of the two are ball-milled prior to pressing.

From 1 to 2% of iron contamination is picked up from the ball mills. Wet grinding causes higher contamination and increased oxidation over dry milling. Improvements are effected by the use of reducing atmospheres or by replacement of water with benzene, but in these cases internal accretions form in the ball mills. The slightly oxidized powder mixture is heated for 3 hr. at or below 700° C. in hydrogen.

Compacts may be pressed cold at pressures up to 50 tons per sq.in. and then sintered at 1450 to 1500° C. in dry hydrogen. Hot pressing up to 12 tons per sq.in. may be done for 10 min. in molds of chromium steel heated to 600° C. Compacting at 1100 to 1500° C. may also be done in hot graphite molds and a hydrogen atmosphere; in such equipment pressure may go no higher than 2500 psi. At the highest temperature, compacting and sintering is done simultaneously.

A representative test may be quoted: A powder mixture 75% smaller than 3 microns is milled 30 hr. in hydrogen followed by 48 hr. milling under water. Its composition is 5.25% C, 0.1% Si, 1.09% Cr, 3.86% Fe, 7.56% Co. It is sintered and pressed simultaneously at 1500° C. and 2500 psi.; the slug then has a Rockwell number of C-92 (60 kg. pressure). From such tests, together with macro and micro examinations of fracture, and porosity or specific gravity measurements, deductions can be made concerning suitability to manipulation by sintering technique. It is emphasized that no tests of this character indicate the practical value of such an alloy. Only operating tests will do this.

By continuing the ball milling process (finer grinding) it becomes possible to work either with diminished cold pressures, lower sintering temperatures, or shorter sintering times. Very fine powders, however, involve the undesirable possibility of large recrystal- *(Continued on page 82)*

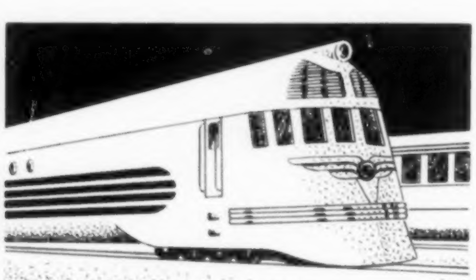
CRITICAL POINTS

a week's diary

UP VERY EARLY to catch the fast train to Detroit which the New York Central Railroad calls The Mercury — any train even pretending to be first class having a name these days. It is a cause for wondering why the other day trains between Cleveland and Detroit rumble along at 43 miles per hr. when it is easily possible to do better with equipment that is not very light in weight.

High Speed Passenger Trains

The Mercury does 60 miles per hr., including a stop at Toledo; the cars are rebuilt equipment, articulated in pairs with three four-wheel trucks to two cars. Much attention was given to the spring suspensions, as the cars ride very smoothly, even through the station yards. Interiors are air conditioned and attractively furnished in the present mode, especially the dining car, arranged to seat comfortably 56 passengers and so handle the large suppertime patronage on the return trip. The kitchen is in the car ahead, and intervening doors operated by an electric eye intrigue the observer. A steam locomotive with brightly colored streamlined shrouding draws the train; the "pants" on the engine are not exactly necessary, for the schedule is maintained by other locomotives when this one is laid up for repairs.



Out to talk with Boegehold, Tobin and Jominy at General Motors Research Laboratory, and then adjourned for lunch with the "Cafeteria Institute of Technology" where the technique of winning football games was discussed, most of those foregathering being University of Michigan alumni, and so interested in the chances that the team could beat its traditional enemy from Ohio State University.

Machining Hardened Forgings

Then to Chevrolet-Forge with Elvin Mann and A. B. Wilson, who told about the development of their practice of machining forgings of S.A.E. X1340 steel hardened and tempered to about Brinell 341. Also learned that at General Motors Truck axle shafts of S.A.E. 4340 were machined at Brinell 400 to 444. Roy Roush of Timken-Detroit Axle Co. wrote later that his firm had standardized on the last-mentioned figures and on occasion had even machined splines on $2\frac{1}{2}$-in. shafts which had been oil quenched and drawn to 500 to 555 Brinell!

That evening to the regular meeting of the Detroit Chapter. After more football talk the gathering split into five groups where discussions were held on various important matters. Harry McQuaid of Republic Steel Corp. was chairman of one group and he insisted that metallurgists were over-emphasizing the hardenability of steel — meaning thereby the depth of hardening — without equal attention to other important properties such as machinability and especially toughness.

Salt Baths

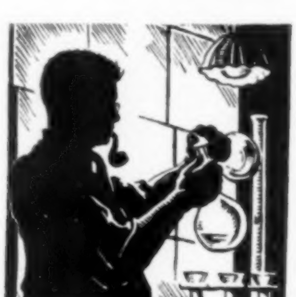
Harry Ford, of the more famous Henry's organization, chairmanned another group discussing salt baths, but most of those present appeared more anxious to acquire information than to transmit it. Fortunately Leon Slade of the Gleason Works of Rochester, N. Y., was present and talked freely of the methods used there for hardening cutters made of high speed steel, a matter cer-

tainly worthy of an extended article in a later issue of METAL PROGRESS.

Next day in Chicago and to Lindberg Engineering Co. to meet Lindberg Jr., Stevenson and Roshong, full of ideas about furnaces for heat treatment in controlled atmosphere. Then to Indiana Harbor where Hunter Nead escorted me about one of the Inland Steel Co. works. Magnificent, as seen at dusk, was the new 44-in. strip-sheet mill, working like a clock, converting in a minute or so a mastodonic slab into a rosy ribbon of steel rippling out from the last roll-stand at half a mile a minute. All this huge aisle as void of men as a city street at midnight, yet packed with unbounded energy. We talked of his new improvement in the machinability of steels by introducing a fractional percentage of lead into the molds during teeming, of the possible health hazards due to lead fume in chimney gases when such scrap steel is remelted either in the foundry cupola or openhearth furnace, and of the difficulty in getting check analyses of traces of lead in the atmosphere, and even of small amounts in the steel.

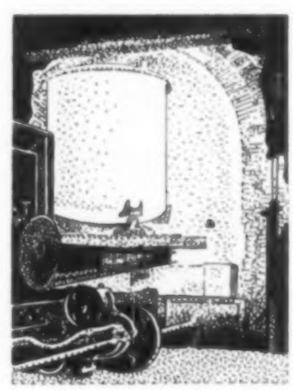
Leaded Steel

As to the latter point, both Charles Morris Johnson of Crucible Steel Co. and C. B. Francis of Carnegie-Illinois Steel Corp. assure me that a good chemist will have no trouble in checking results on a given sample (as there are at least four rather simple and very accurate methods for determining lead in steel) although a routine analyst might get funny results until he became accustomed to the precautions necessary. Tom ("How About the Sampling") Wright of Lucius Pitkin, Inc., emphasizes that unusually large segregation in lead may be expected throughout a single ingot as compared with the other elements. Lead has a density about 1.5 times that of liquid steel and a boiling point below tapping temperature and forms no alloy with iron or the other elements usually added. Hence the mill analysis and the check by the purchaser may both be accurate, yet considerably different.



Up to Milwaukee on another "name train" which carried a lounge car the daddy of them all, doubtless very swank-o for visitors to the Columbian Exposition, replete with an oaken colonnade and black leather upholstering — and a Millet sylvan scene embroidered in needlepoint, framed resplendently at the end. It should be a museum exhibit within the austere tower sheathed in aluminum and glass, built by A. O. Smith Corp. for the engineering and research departments. There met Sam Hoyt and Merrill Scheil and another visitor, John Stokely from Standard Oil Co. of California. We talked of 18-8 stainless steel used in the petroleum industry. Stokely said his firm had innumerable 18-8 tubes in cracking still service, and those ten years old were still as good as new. Some occasional failures were by intergranular cracking and oxidation leading inward from the fire side. Several explanatory hypotheses have been advanced, none of which fit all the facts and explain why, now and then, a tube develops surface cracks whereas all its neighbors are unscathed.

Difficult Corrosion Problems



Hoyt told of another case of unexplainable variation in commercial 18-8 sheet (the type with some molybdenum added). Several tons of it were bought to line a number of vessels; the chemical analysis was chosen after tests showing it to be immune to the liquid being processed. At the very end of the job, a shortage developed and enough more sheet to line two or three nozzles was supplied from stock. In service the nozzle linings crumbled quickly; all the rest of the sheet has been perfectly satisfactory. The two lots of 18-8 are indistinguishable chemically, physically, and metallographically. The metal in the linings has been found to resist phosphoric acid, and the nozzle

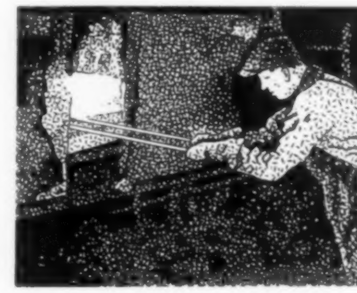
material does not — and this is now an added acceptance test for 18-8 in that particular service — quite pragmatic, for there is no phosphoric acid in the liquids being handled. Sam Hoyt's flesh must creep when he thinks that he *might* have gotten hold of the wrong material first.

As long as such unexplainable variations exist in stainless the producers can expect important customers to demand literally "tailor made" alloys for each special purpose. On the other hand, abolition of several current varieties is even now the aim of steel makers, and definite recommendations along this line were recently made by a technical committee headed by Lewis Bergen of Crucible Steel Co. of America. John Van Deventer, editor of our aged contemporary *The Iron Age*, predicted that the present annual output of 100,000 to 125,000 tons of stainless ingots could go to one million within the next decade if producers would pool their research activities and cooperate in vigorous promotional campaigns. These speeches, together with another by Dr. Krivobok of Allegheny-Ludlum on the early history of stainless, were made at a later date in Pittsburgh, when the Stainless Steel Committee met to celebrate the 25th anniversary of Brearley's discovery with a feast and a symposium at most resplendent banquet tables. Of the American pioneers, happily Messrs. Becket, Johnson, Armstrong, Clark and Browne were present and in good health.

Limitation of Types

Next, to Allis-Chalmers plant were Harold Stein showed a modern weldery, busily constructing heavy machine frames of steel plate, and an enormous old foundry where the work used to be done, but now largely filled with mechanized units for mass production of gas engine and tractor parts. In the heat treatment department are several furnaces of his own design he calls an "umbrella furnace". These are turrets with domed top, built in a round steel casing. The hearth rotates, carrying the load from charging door around and back to the same door for discharging. The hearth has a central hole above a vertical fire port, and up which comes the heating flame; the hot gases spread out in all directions on hitting the crown of the roof, and are drawn off at small flues spaced around the wall at hearth level. Not only is there no cold spot near the door, but the scaling effect of the atmosphere can be controlled somewhat by the position of the gas burner, up or down, in the entrance port. Ordinarily, combustion of the fuel gas (butane) should reach completion only at the instant the gases reach the exit.

Umbrella Furnace



On Friday by train to the University of Wisconsin at Madison, where a group at the Faculty Club made good luncheon conversation. Professor Withey was interested in the uniformity of the new strong structural steels; McCaffery, Oesterle and Ragatz in everything from ore to finished metal. The metallurgical faculty has had a windfall — a fine building formerly occupied by the Forest Products Laboratory. My host, Edward Bennett, professor of electrical engineering, then demonstrated his new discovery of the "proximity effect" — localized heating of metal by alternating currents of radio frequency. If such a current is led through a water-cooled copper tube, and this is placed close to but not touching a steel plate, induced currents rapidly heat the steel immediately beneath; the effect is more intensely localized the higher the frequency of the fluctuating current and its wattage. It follows that if two sheets of steel with matched edges separated 0.10 in. or so, are short-circuited at one end and the others connected to the circuit in series, the oscillating currents will hug the adjoining edges which are rapidly brought to the welding heat. He and his research assistant, G. I. Goumeniouk, made a butt weld between two 1/4 x 6-in. bars; the 30,000-cycle current at 2400 amperes and 20 volts, but with an input of 14 kw., was on for 18 sec. before the grips squeezed the ends together. A number of interesting properties of this current were also demonstrated: The forces acting across the gap are repulsive, so that irregularities in spacing tend to equalize. Likewise, any arc struck between the adjacent edges is driven by the magnetic field with great speed toward regions of lower potential, where it is snuffed out.

A New Welding Method

CORRESPONDENCE

from home and abroad

European Welding Practice
as viewed by an American

East Pittsburgh, Pa.

To the Editor of Metal Progress:

Returning from a trip of several weeks in England and on the Continent, during which a special effort was made to view important welding work, one arrives at the generalization that the fabrication art and design is being developed as rapidly over there as in the United States. In all instances economic and industrial conditions shape the commercial utilization.

For instance, production in Europe is generally not as large in volume as it is in the United States; consequently there is not the demand for the expensive automatic welding equipment in use in the United States. This probably accounts for the more rapid development and extensive use of special welding processes in America. Likewise, design details are often specified by the purchaser abroad, and each purchaser has his own requirements. Consequently, it is not as easy to standardize on design as it is in the United States, which condition interferes with high production.

Another economic influence is that wage scales of European workers are lower, while raw materials are somewhat higher than they are in the United States. This condition frequently makes it uneconomical to use many of our labor-saving devices, such as welding manipulators.

Finally, many of the materials in use in America are not commonly available in Europe; consequently the engineer does not have as much to choose from in designing a structure.

Arc welding is the most widely used welding process in Europe. Coated electrodes are used almost exclusively in England and have been for many years. In Holland nearly all electrodes are of the coated type while in Germany the major portion of the electrodes are of the bare types. In France both bare and coated type electrodes are used as well as large quantities of washed and lightly dipped electrodes. Cored type electrodes are also frequently used on the Continent.

The trend in Germany is undoubtedly toward coated type electrodes but at the present time their most extensive use seems to be confined to companies manufacturing electrodes for their own use. The possible explanation for the extensive use of bare type electrodes in Germany lies in the fact that they are accepted by the German State Railways and the Navy. Inasmuch as these two organizations are considered to be leaders in engineering, other machinery manufacturers tend to follow.

General design practice in Europe is similar to that in the United States. The external appearance is frequently quite different but a close analysis indicates a great similarity in the nature of the joints.

Most striking is the large variety of welded products; many small items are all arc welded

even though this process does not appear to be the most economical. There are two possible reasons for this condition:

1. It may be assumed that the use of welding is in the stage which many American industries passed through several years ago. The advantages of welding become so obvious after it is used awhile that designers become over-enthusiastic and attempt to weld everything.

2. A second reason is the limitations of other satisfactory methods of manufacturing small or complicated parts. Delivery dates are important; consequently it is often impractical to have castings made even though they might seem more desirable. Most companies do not have equipment to make pressings, and die cost and deliveries from outside suppliers again exert a tremendous influence. Also the low labor cost and low production of a single design makes it impractical to spend very much on tooling-up.

Another important design item is the extensive use of small parts even on large equipment. It appears as if not enough time was given to a thorough analysis of the problem in order to eliminate unnecessary work. Furthermore, the inability to obtain large rolled shapes has often required the designer to build up steel parts from smaller sections. This condition, although unavoidable, requires large amounts of extra welding to replace the heavy shapes.

There is a notable trend in Europe toward fabrication of structures from pre-machined parts in order to eliminate expensive final machining. Structures of this type have been fabricated by the English Electric Co. within tolerances of 0.008 in. Work of this type requires accurate, heavy fixtures and very close welding procedure and control.

Annealing of welded structures is seldom done in Europe except for pressure vessels and parts which must not distort. Rotating equipment, railway car trucks and underframes are seldom if ever annealed for stress relief before being placed in service.

To summarize — the applications of welding in Europe and America are similar, thereby indicating that its economic and engineering advantages are recognized on both continents. Many products, machines and structures are being fabricated at the present time but there are many large fields ahead for welding to conquer.

Charles H. Jennings
Engineer in Charge of Welding Research
Westinghouse Electric & Mfg. Co.

Effect of Aluminum on Inclusions
in Steel and Cast Iron

Paris, France

To the Editor of Metal Progress:

In a preceding letter on the formation and evolution of inclusions in steel (Metal Progress, May 1933) we noted that the various additions to the bath during refining may, by altering the chemical nature of the inclusions, modify their form, number and distribution — in short, metamorphose the inclusions, to use a term from geology. It might be useful to complete the discussion and illustrate this phenomenon in steel and cast iron by some characteristic examples of practical importance.

In particular, certain additions may either coalesce existing inclusions — that is, reunite or assemble them — or, inversely, they may divide and disseminate them into finer particles. These opposing actions have each their advantages and their disadvantages. For example, the coalescence of sulphurous inclusions resulting from the addition of manganese to steel and of magnesium to nickel is thought to be responsible for good forgeability in the ingots; these additions transform the sulphide films, which otherwise would form a network throughout the metal, into dispersed particles.

A different and important action results from the addition of aluminum to a metal containing silicates in the form of more or less rounded, fusible particles. A little aluminum may react on these inclusions and cause the precipitation within their mass of small crystalline constituents as very fine, more or less angular particles (recently observed by Castro and Portevin, Amberg and Hultgren).

In reality, the modification in shape and distribution varies with the process of formation and the initial nature of the inclusions, as indicated in the attached diagram. This drawing shows that by adding aluminum to a meta! containing globular, vitreous inclusions of basic silicates the following alternatives may be obtained:

1. Superficial reaction, with formation of particles consisting of a phase rich in silicon, followed by crystallization on cooling into aluminum silicate or silico-aluminates of iron and manganese, these replacing the initial vitreous silicate partially or almost entirely.

2. Superficial reaction with formation of a shell of aluminum silicate crystals, resembling on micrographic examination a ring or horse-

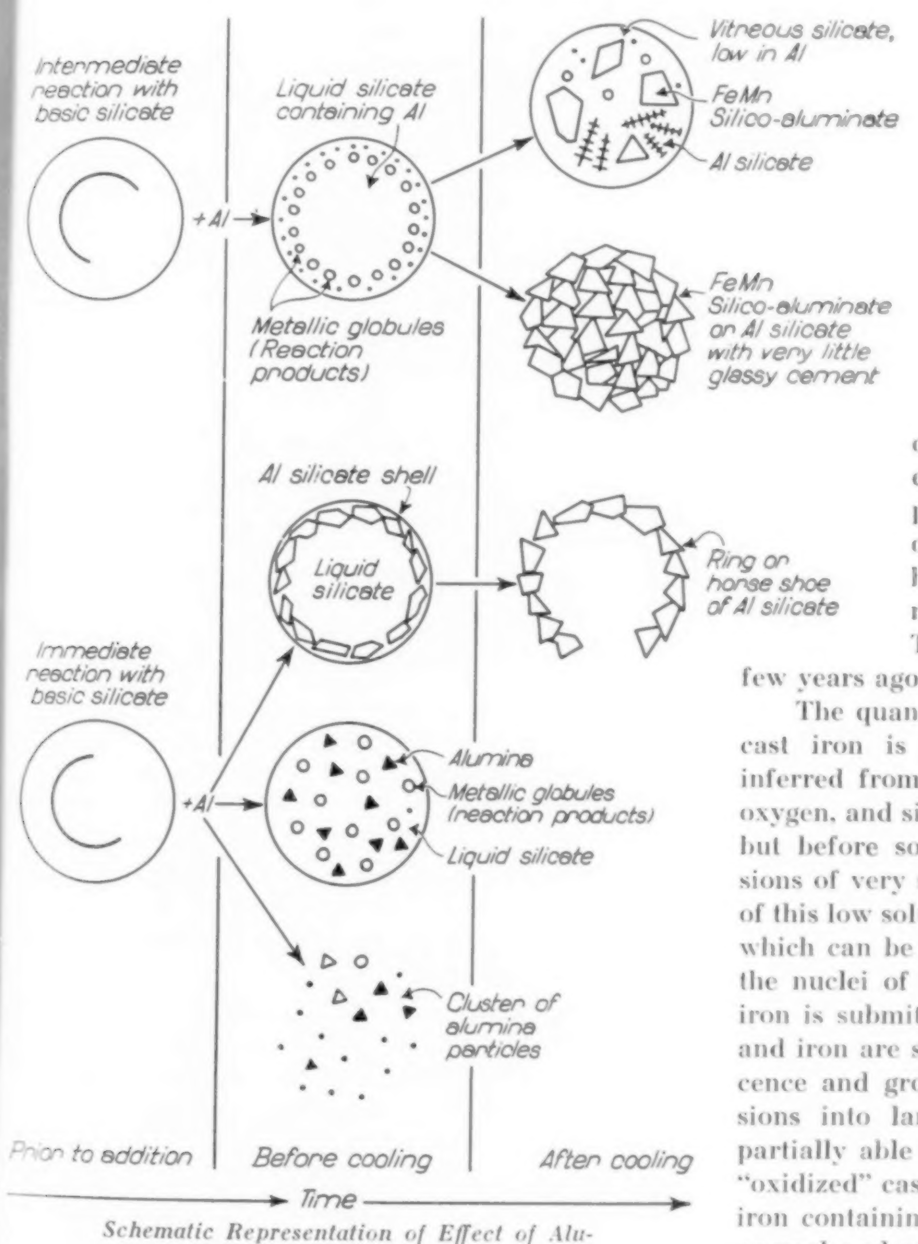
shoe of irregular crystals, with or without a vitreous residue.

3. Total destruction, giving more or less scattered clusters of alumina or aluminum silicate.

These various lines of action depend upon the initial composition of the inclusion and, consequently, upon the percentages of silicon, manganese and oxygen in the steel, as well as upon the conditions existing when the aluminum is added to the liquid metal, such as the quantity added and the temperature.

If we also consider that aluminum can modify the aspect and shape (morphology) of sulphurous inclusions by reducing the oxides and silicates associated with the sulphides, and bearing in mind the effect of aluminum on killed steel, we can see what complex effects the addition of aluminum may have and how difficult it is to segregate these various effects in order to explain the final result on the steel.

Dissolved aluminum has certain simultaneous specific effects such as elimination of blowholes, influence on dendritic segregation, modification in nature, number and shape of inclusions, and its effect upon the primary and secondary crystallization of the metal. The effect upon primary crystallization is a result not only of the quiet solidification (smaller gas evolution) but also of the action of aluminum on the inclusions. Size and shape of the inclusions may act in various ways; for instance, coalescence of inclusions favors their flotation to the top, while dispersion of particles tends to increase the fineness of the structure by increasing the number of solidification nuclei.



Schematic Representation of Effect of Aluminum on the Form and Nature of Basic Silicate Inclusions in Steels and Irons

This effect of inclusions on crystallization and supercooling provides a hypothetical explanation of the pronounced action of aluminum on the graphitization of cast iron during solidification, especially when the cast iron has previously been submitted to an oxidizing action to increase its hardening power (retain carbide rather than produce graphite). The interpretation as we gave it a few years ago is as follows:

The quantity of oxygen dissolved in liquid cast iron is extremely small, as would be inferred from the equilibrium of carbon with oxygen, and silicon with oxygen. Upon cooling, but before solidification, finely divided inclusions of very small mass precipitate as a result of this low solubility of oxygen, but in a number which can be under rough control. These are the nuclei of graphitization. Now, if the cast iron is submitted to an oxidizing action, silica and iron are slagged and this induces a coalescence and growth of the finely divided inclusions into larger ones, less in number and partially able to rise to the surface. So-called "oxidized" cast iron would, in reality, be a cast iron containing fewer non-metallic nuclei than normal and more prone to supercooling. Oxidation also eliminates some carbon in the form

of carbon oxide, and this influences mechanically the coalescence of the nuclei. Whenever cast iron is submitted to extremely oxidizing conditions (as by the addition of Fe_2O_3 or blowing with air), the tendency would be toward a decrease in number of nuclei by growth, coalescence, decantation, and a corresponding decrease in graphitic carbon — even without any loss of silicon, the graphitizing element.

On the other hand, the addition of a deoxidizing agent such as aluminum to a cast iron deprived of its non-metallic nuclei creates new nuclei by displacing the metal-oxygen equilibrium toward still lower values and by the formation of extremely fine inclusions. Of course, we have no actual proof of this, but it seems to me to tally well with all the facts, and can be correlated, for instance, with the fact found by Murakami and German authors that a killed cast iron solidified in vacuum and after a prolonged stay, tends to become white.

ALBERT PORTEVIN
Consulting Metallurgist

Bronze or Iron?

NIAGARA FALLS, N. Y.

To the Editor of METAL PROGRESS:

Referring to Mr. Collitt's doubts (METAL PROGRESS, December 1938, page 710) about the kind of metal being cast in the ancient foundry pictured on the December cover of METAL PROGRESS, the type of fracture of the scrap leads to the belief that the print shows an iron foundry.

CHARLES O. BURGESS
Union Carbide & Carbon Research Laboratories

Permanent Magnet Alloys of iron, nickel and aluminum

KÖLN, GERMANY

To the Editor of METAL PROGRESS:

In less than ten years the magnetic alloys invented by Dr. T. Mishima have had an outstanding development. Researches by different investigators on the microstructure have given us a clear idea of the mechanism of their mechanical hardness and magnetic power. These phenomena appear to be associated with the precipitation of crystals, which in the state of greatest magnetic hardness are scarcely visible under the microscope. The speed with which this crystallographic separation proceeds is somewhat low, yet the degree of undercooling of the parent solid solution is of particular importance. In the iron-nickel-aluminum alloys free of copper and cobalt the highest magnetic power is secured only in an intermediate state between the full suppression of reaction (fixation of unstable solid solution) and the beginning of visible precipitation. Such a state demands a carefully controlled cooling, as in a blast of air.

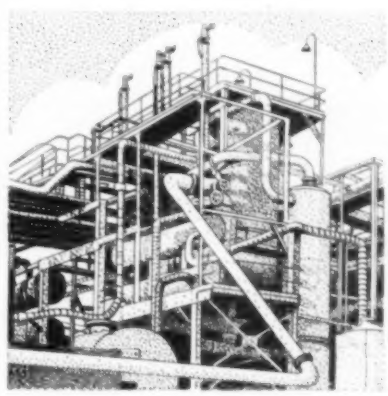
Melting is preferably done in acid-lined, high frequency furnaces and demands special operating conditions because of the reaction between metal and furnace lining. If a basic refractory is used, an aluminum-rich accretion grows excessively on the furnace lining. If the component alloys are melted separately and added in a mixing ladle, aluminum shows a positive heat reaction on mixing. The castings are poured advantageously, but not exclusively, in green sand molds.

The exact alloy used depends on the desired magnetic properties; usually excellent values can be had from the ternary iron-nickel-aluminum alloys in the as-cast condition, by simply harmonizing the composition with the mass of the casting. Values so achieved are scarcely surpassed after special precipitation hardening. An alloy containing 25% nickel and 15% aluminum in pieces of about ½ in. wall thickness may have, in the as-cast condition, residual magnetism of about 5600 gausses with coercive force of about 500 oersteds, while after the most favorable heat treatment they showed 6200 gausses and 495 oersteds. Some idea of this superiority may be had from the criterion proposed by K. L. Scott in his article on Permanent Magnet Alloys in Metals Handbook — namely, that the product of residual magnetism by coercive force can be used as a measure of magnetic quality. This product for the standardized chromium magnet steels is about 625,000; for the best commercial cobalt steel quoted by Mr. Scott it is 2,300,000; for the Mishima alloy as cast 2,800,000; for the same in the heat treated condition 3,070,000.

With further additions of cobalt or copper or both, the iron-nickel-aluminum alloys show a more complex and easily observable mechanism of precipitation hardening. As cast, these alloys are not useful because of their low magnetic values and they always require a double treatment composed of an accelerated cooling and a precipitation anneal. The necessary cooling speed increases with the cobalt content.

With more than 5% cobalt, further cobalt additions are less effective than copper. Both silver and tin may be substituted for some cobalt or copper in these alloys. The supposed necessity of melting with special precautions to eliminate the normal impurities in the iron has not been fully confirmed by late researches.

As to the magnetic power, an alloy with from 5 to 6% cobalt shows from 6250 gausses with 560 oersteds, to 5300 gausses with 760 oersteds (product 3,500,000 to 4,000,000). The same alloy with a further copper addition of 5% had 5400 gausses residual magnetism with 800 oersteds coercive force (product 4,320,000).



In neither the as-cast nor precipitation-hardened condition are the alloys machinable. After a special, patented annealing treatment they become machinable by high speed steel or hard faced tools. Their Brinell hardness number then increases from 280 to 350, yet hard crystals and accumulations of alumina in little intergranular hollows causes rapid tool wear.

To manufacture complicated shapes, which may be cast only with great difficulty or not at all, a very useful process has been developed. Finely dispersed magnetic material in the heat treated state is pressed with organic bindings like bakelite in the desired form. In this way excellent magnetic values are secured — coercive forces from 600 to 750 oersteds with very high remanences of 6500 gausses and more (product about 4,500,000).

HANS LEGAT
Metallurgical Engineer

Failure of Still Tubes

MANCHESTER, ENGLAND

To the Editor of METAL PROGRESS:

In the very interesting article on the above subject by Messrs. Wright and Habart in your November magazine, some statements made by me before the International Association for Testing Materials were questioned as being needlessly conservative, and even erroneous, in view of the very rare findings, by those two American metallurgists, of intergranular failure of ferritic steels in high temperature, high pressure service.

My statement about the mode of failure of high creep resistant steels, which Messrs. Wright and Habart quote, has the following basis of experimental findings:

(1) Molybdenum steels and most other steels, when in a condition possessing high creep resistance, and if tested under creep conditions to fracture, fail by intercrystalline cracking.

(2) Investigation at the British National Physical Laboratory upon the failure of molybdenum steels under creep conditions has continued to stresses (as low as 6720 psi.) approaching working stress magnitudes and for very long periods. The results of this investigation, which are yet to be published, clearly indicate that intercrystalline cracking with low ductility may be anticipated under working conditions if continued long enough to produce fracture.

Carbide spheroidisation in molybdenum steels is accompanied usually by improved ductility under creep conditions, but also by a considerably reduced resistance to creep, and in such a condition the steel could hardly be regarded as falling in the category of "high creep resisting steels".

If a molybdenum steel when put into service has high creep resistance but the temperature is such that appreciable weakening by thermal action occurs before intercrystalline cracking is initiated, it is possible that improved ductility would be available. Unfortunately evidence obtained by the National Physical Laboratory in this investigation indicates that cracking may be detected at extensions of between 1 and 2%. For this reason I still consider that, for reliable service over long periods where high creep resistant steel is essential because of the working stress, it is unwise to design for a greater creep strain than 0.5%.

The writer would agree with Messrs. Wright and Habart that the published N.P.L. tests made at 20,000 to 34,0000 psi. would not, by themselves, be sufficient to determine information for design but, as indicated above, the actual range of investigation has extended to much lower stresses and much consistent data have been obtained. It is hoped that this will be available and published before long.

R. W. BAILEY
Research Department,
Metropolitan-Vickers Electrical Co., Ltd.

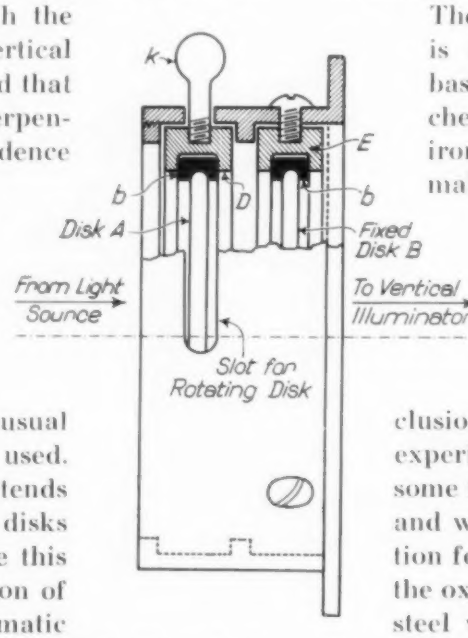
Device to Regulate Intensity of Metallographic Illumination

CLEVELAND, OHIO

To the Editor of METAL PROGRESS:

Regulation of the intensity of illumination of a micrographic specimen for visual observation offers quite a problem, and regulation is too frequently done by restricting the pencil of light, with serious damage to quality. The use of neutral filters such as a dark blue cap fitting over the observation ocular is satisfactory for quality, but the probability of achieving optimum intensity is slight.

We have solved this problem to our satisfaction by the use of two Polaroid disks, rotating one against the other. The disks are the standard glass-mounted, bakelite-bound style, approximately 2 in. in diameter; a mounting cell as sketched holds one firmly while the other can be rotated from one position, where its vibration plane is parallel to the other, through 90°. The device is placed on the cool side of the water cell, preferably with the fixed glass nearest the vertical illuminator and so mounted that its vibration plane is perpendicular to the plane of incidence of light upon the vertical illuminator (although this detail is not all-important). At maximum, about 26% of the white light is passed; at minimum, practically none (0.2%), so little that the usual dark lens cap need not be used. The color of the light tends toward the red end as the disks are fully crossed, but since this is due to greater suppression of blue, the usual monochromatic filter gives all the correction desired. No polarization effect is found, since both disks are together, neither being in the necessary position to analyze the light.



From the sketch the construction should be obvious. Polaroid disks *A* and *B* are held in clamp collars *D* and *E*, which probably could be dispensed with if the bakelite rings *b-b* were thicker and smooth on their outside diameter. Collar *E* is held fixed by three screws; collar *D* may be rotated by knob *K* in a 90° slot.

GORDON T. WILLIAMS
Metallurgist, Cleveland Tractor Co.

The Abnormal Structure in carburized steels

SENDAI, JAPAN

To the Editor of METAL PROGRESS:

"Abnormal" structure in slowly cooled specimens and of soft spots in quenched specimens are frequently found in carburized hypo-eutectoid steels. Many important investigations on this subject have been made, especially in the United States, following the classic paper of McQuaid and Ehn. [See page 44 of this issue.] There now exist two hypotheses on the cause, namely *(a)* oxygen and *(b)* high purity iron. The oxygen hypothesis, which is the older one, seems to be based upon the observation that the structure of steel becomes "abnormal" when it is carburized with an oxygen-containing carburizer, such as carbon monoxide gas, while the structure of the same steel is "normal" when the carburizer is a hydrocarbon, such as methane or benzene; also that an incompletely deoxidized steel shows the abnormal structure.

The high purity iron hypothesis, which is developed recently in Germany, is based upon the fact that the structure of chemically pure iron, such as carbonyl iron or electrolytic iron, becomes abnormal after carburization, the coalescence of the eutectoid cementite being remarkable.

In order to check the above theories, the present authors repeated published experiments and arrived at the conclusion that the both theories are experimentally correct. Hence we made some further experiments along a new line, and would like to propose a new explanation for the oxygen hypothesis, that is, that the oxygen acts as a purifier for the normal steel which contains more basic elements than iron. The oxygen theory thus conforms very well with the high purity iron theory in essence, only the mode of expression being different.

The main results of the present authors' investigation will be briefly explained:

1. In the abnormal structure found in the slowly cooled hyper-eutectoid zone, thick primary cementite crystals are surround by zones of ferrite, the lamellar pearlite also being somewhat coalesced. When such a steel is quenched, soft spots occur, due to the formation of troostite at Ar′. Thus the abnormal structure and the

soft spots come from the same origin and consequently ought to be explained by one theory.

2. The formation of the abnormal structure results from the coalescence of the cementite, and the formation of the soft spots is due to the fact that the velocity of the A_1 transformation of the steel in question is relatively large as compared to its cooling rate through A_1.

3. The tendency of cementite to coalesce and the velocity of the steel to transform are affected by the viscosity of the alpha and the gamma solid solution. When the steel contains less elements in solid solution, its viscosity is also less. Hence when the steel is pure in the sense of having a low content of elements going into solid solution (non-metallic inclusions are excluded in this discussion), the coalescence of cementite can easily take place and its A_1 transformation velocity may be large, thus easily inducing the abnormal structure and the soft spots in such case. Hence the pure iron theory may be said to be correct, as it satisfactorily explains abnormal structures and soft spots.

4. The formation of abnormal structures and soft spots depends not only upon the viscosity, that is, the purity of the steel, but also upon the cooling velocity through the critical range. When that velocity is large, it favors the formation of normal structure both in samples relatively slowly cooled and quenched; when it is small the reverse is true. Consequently the normal and abnormal structures may be obtained at will by properly controlling the cooling velocity, irrespective of the purity of the steel. The same may be said about the formation of soft spots. It may also be said here that, given the same purity and cooling velocity, the fineness of the grain size also favors abnormality.

5. The oxygen theory may be considered as valid only when the steel is purified by the action of oxygen, that is, the impurities in steel more basic than iron, such as manganese or silicon, are eliminated from solid solution by the action of oxygen. (Here the non-metallic inclusions are, as already stated, out of consideration.) In the ordinary carburizing process, using a cement containing oxygen, the greater part of such basic elements forming solid solution in the outer layer of the sample are oxidized and segregate as oxide, leaving behind the iron solid solution in a purer state; thus the abnormal structure and soft spots are induced. However, when the steel contains nobler metals than iron, such as nickel or cobalt, oxygen may react with iron but not with nickel or cobalt, and since no purification of the iron takes place, it retains a normal structure.

6. It is frequently observed that incompletely deoxidized steel shows an abnormal structure. The cause of this is generally attributed to the action of residual oxygen in the steel, but this, we believe, is not a correct interpretation of the phenomenon. As the residual oxygen (in incompletely deoxidized, solid steel) is in the form of iron oxide or solid solution and the main part of this oxygen can be removed by reduction in the first period of the carburization process, the structure of the carburized steel before carburization has no significance. Hence the residual oxygen can not be taken as the cause of abnormal structure appearing in incompletely deoxidized steel. This phenomenon, on the other hand, may be interpreted as follows: When deoxidation is incomplete, all the deoxidizer added to the bath is converted into its oxide and slags or forms inclusions and therefore scarcely enters into the steel as a metallic constituent; the iron thus remains in a purer state than though enough deoxidizer were added so that some silicon or manganese enters into the steel as a metallic constituent after proper deoxidation. Hence if the pure iron, in such case, contains not any or but a slight amount of other metallic elements, it may induce the abnormal structure.

7. The abnormal structure in steel deoxidized with aluminum may also be explained as above. As it is a very powerful deoxidizer as compared to manganese or silicon, only a trace of it enters into the steel in the metallic state after proper deoxidation, and so the steel remains purer than though the steel were contaminated by ferromanganese or ferrosilicon. Therefore when such steel is carburized the abnormal structure appears.

8. The steel deoxidized with aluminum

has often a fine-grained structure, and this fact has been known to bear a close relation to abnormality, but they are really independent of each other, as pointed by Dr. Houdremont. Refinement of the grain size is to be attributed to the presence of very fine particles of Al_2O_3 distributed in the matrix of austenite, while the abnormal structure, in this case, is attributed to the *purity* of the solid solution in respect to metallic solutes, although the fineness of the grain size favors the formation of abnormal structure to some extent.

9. As has been stated above all the observed phenomena concerning the present problem are satisfactorily explained and none is left unsolved.

It may be concluded that to prevent the formation of abnormal structure and of soft spots in steels of good commercial grade, the cooling velocity must be made somewhat greater than when heat treating the normal steels.

KEIZO IWASE
MASAO HOMMA
Metallurgical Faculty
Imperial University

Artistic Metal Work
on a heroic scale

SAN FRANCISCO, CALIF.

To the Editor of METAL PROGRESS:

Your readers may be interested in a piece of gigantic sculpture prepared for the 1939 Golden Gate Exposition. It is made in the same general way as the much larger and more famous Statue of Liberty — that is, it is a thin sheet of formed metal supported by an interior skeleton structure of steel columns, beams and bars. Certain important differences other than size may be noted: The Statue of Liberty is made of sheet copper for permanence, and all joints are riveted or soldered, whereas the giant Phoenix is of Armco iron sheet with welded joints and the whole bird gilded with gold leaf for color.

The work was copied from a small clay model prepared by sculptor Olaf Malmquist. The idea of immortality is inherent in the mythological Phoenix, which, after its life span, is consumed in fire by its own act and then rises in youthful freshness from its own ashes. In this application, of course, it symbolizes the rise of San Francisco from the ashes of fire and earthquake. It tops the Tower of the Sun, on Treasure Island in San Francisco Bay, and will serve as the "theme piece" for the Exposition.

The bird is undoubtedly the largest iron figure ever made in the West. It is 22 ft. high, weighs more than 5000 lb., and is made up of 700 separate hand-hammered pieces of 14, 16 and 18-gage Armco ingot iron.

Wing spread is 21 ft. across and the wings are folded; from shoulder to where the wings rejoin the body is a curve of about 17 ft. Construction required the full time of nine craftsmen for 60 days. The 700 sections were welded into one whole by 6800 ft. of electric welds; this had to be done piece by piece, and any warp, twist and buckle was carefully smoothed out before proceeding.

The ingot iron worked beautifully. We had to "whale the daylights" out of certain parts to get the exact shape and contour required for the head, beak, deep-set eyes, and some of the fancy scroll work, for instance. It was necessary to anneal only on the most difficult parts, where excessive hammering hardened the sheets unduly. A quick application of heat from a gas blow torch brought it immediately back to softness and pliability.

Statue of Heroic Size Constructed of Metal by Methods Known to Ancient Artificers — Except for the Modern Welding Process

The Phoenix was assembled around an 8-in. H-column from which sprouted a cobweb of reinforcing braces. After completion it was cut into five sections, moved to Treasure Island, and rewelded around a duplicate H-beam anchored firmly into the Tower of the Sun.

JOHN FOSTER
Artistic Metal Works

ECONOMY — WITH A MORAL

FLAME HARDENING of steel where exceptional wear resistant properties are required is a comparatively new process, but the economies resulting from its application in conjunction with Molybdenum steels, are most significant. They are graphic proof of the cash value of constantly re-studying your production processes and material specifications in the light of improved methods.

When high wear resistance plus good physical properties are required, flame hardening makes the use of relatively inexpensive alloy steels possible. Molybdenum steels, particularly SAE 4140, 4150 and high Carbon (0.40-0.50% C) Manganese Molybdenum, are exceptionally suited for flame hardening. They are practically fool-proof. Molybdenum (next to Carbon) is the most effective hardening agent normally added to steel.

Molybdenum steels and irons make production dollars go farther in many ways. Our technical books, "Molybdenum in Steel" and "Molybdenum in Cast Iron," will be gladly sent free to any interested production executive or engineer.

PRODUCERS OF FERRO-MOLYBDENUM, CALCIUM MOLYBDATE AND MOLYBDENUM TRIOXIDE

MOLY

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PERSONALS

R. G. Drinnan, Jr., formerly with National Tube Co., McKeesport, Pa., is now with Youngstown Sheet and Tube Co., Youngstown, Ohio.

Bernard L. Schwaller, Rensselaer '38, is with Durabla Mfg. Co. as sales engineer.

Made designing engineer for Kimberly Clark Corp., Neenah, Wis.: **R. Lee Homsher**, formerly sales engineer for Allis-Chalmers Mfg. Co.

C. T. Williamsen, formerly district representative for the Torrington Co., Dayton office, is now associated with the Hyatt Bearings Division of General Motors Corp. in the metallurgical department.

Promoted: **Arden L. Knight**, vice-chairman, Boston Chapter, to district manager of sales in New England for Wheelock, Lovejoy & Co., Inc.

Charles E. Morgan, Jr. has been transferred from United States Steel Corp. Research Laboratories in Kearny, N. J., to the new Irvin Works of Carnegie-Illinois Steel Corp. as metallographer in the sheet mill laboratory.

Harold H. Strauss is now working in the stress analysis department of the Northrop Division of Douglas Aircraft Co., El Segundo, Calif.

John L. V. Bonney, Jr. has resigned from the observation corps of Carnegie-Illinois and is now in the technical division of E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.

J. W. Frame has finished Bethlehem Steel Co.'s student training course and is now permanently stationed at their Lackawanna Plant.

Gustav E. Guellich, formerly with United States Steel Corp. Research Laboratory at Kearny, N. J., is now metallurgist for George Scherr Co., Optical Division, New York.

Alfred K. Martin has temporarily retired to regain his health after 29 years continuous service with Ludlum Steel Co.

Robert W. Lindsay is now employed by the Association of Manufacturers of Chilled Car Wheels at Chicago.

Rolland S. French, M.I.T. '38, is now working as laboratory assistant for Bridgeport Brass Co.

Albert R. Pfeltz, Jr. is now representing Carnegie-Illinois Steel Corp. as resident representative in Syracuse.

Charles A. Conlin has been appointed metallurgist at Memphis plant of Standard Brake Shoe & Foundry Co.

PERSONALS

Ross B. Hopkins is now with Weirton Steel Co. in the metallurgical department.

George A. Bouvier has abandoned consulting work to accept a position with General Cable Corp. as director of manufacturing development for all plants.

Assigned to observation corps at Duquesne plant of Carnegie-Illinois Steel Corp.: **R. E. Butterfield**, formerly graduate assistant in the metallurgy department at Case School of Applied Science.

W. P. Wallace has been transferred from research assistant, United States Steel Corp. Research Laboratory to Columbia Steel Co. as junior metallurgist.

Howard J. Booth, formerly connected with Jones & Laughlin Steel Corp., has accepted a position as foreman with Allied Metals, Inc., Niles, Ohio.

Donald G. Foot is at present employed in the flotation department of the Magna plant of the Utah Copper Co.

Bruce S. Old received a doctor of science degree in metallurgy from M.I.T. in June 1938 and is now in the development and research department of Bethlehem Steel Co.

Robert W. Wilson announces the opening of his own office in Cleveland for the practice of patent law, closing his association with Fay, Oberlin & Fay.

Transferred: **E. K. Waldschmidt**, from the Detroit office of Jones & Laughlin Steel Corp. to the Pittsburgh plant as assistant Metallurgist.

Frank W. Paine, formerly radiologist for Claude S. Gordon Co., is now on the staff of Kloster Steel Co., Chicago.

Now heading his own engineering organization in Chicago: **Clayton E. Plummer**, formerly technical director of chemical and metallurgical engineering for Robert W. Hunt Co.

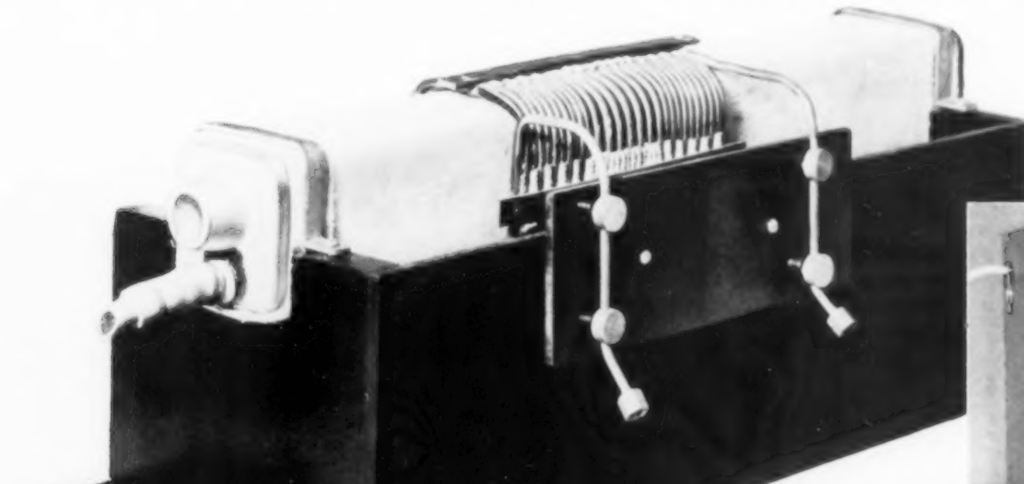
Wilbur R. Varney has been assigned to the Maryland plant of Bethlehem Steel Co.

Appointed research associate professor of industrial engineering at University of New Hampshire: **Daniel S. Eppelsheimer**, formerly with Union Carbide and Carbon Research Laboratory, Niagara Falls, N. Y.

Recent appointments at Gary Works of Carnegie-Illinois Steel Corp.: **Erle G. Hill** as assistant to general superintendent in charge of technological coordination; **John J. Golden** as superintendent of steel production; **Robert A. Peterson** as superintendent of the salvage department.

Announcing . . . A Development of Paramount Importance To The Field Of ***Powder Metallurgy***

INDUCTION FURNACE SINTERING OF METAL POWDERS AT EXTRAORDINARILY HIGH FREQUENCIES



View of High Frequency Sintering Furnace

Steel gear from powders sintered in high frequency furnace

Lepel High Frequency Power Converter

HARDY METHOD OF INDUCTION SINTERING

For many years we have conducted extensive experiments in the induction sintering of metal powders at frequencies far in excess of those ordinarily employed in the melting and heat treating of metals. In this work Lepel High Frequency Converters were employed. The results obtained were so remarkable that special furnaces have been designed. These furnaces and converters are now available to all those who employ Powder Metallurgy methods either for experimental or for production work. Batch or continuous methods may be employed with or without controlled atmospheres.

REDUCTION OF SINTERING PERIOD

In induction sintering the object is heated by induced current. At specially high frequencies the induced eddy currents greatly accelerate the diffusion or alloying of the component metals. The sintering of three or four elements to form an alloy often requires 25, 50 or 100 hours by the usual electric resistance furnace methods. In many instances high frequency induction sintering reduces such periods to a matter of two to three hours. The period required for sintering bronzes has been reduced from one-half hour to five minutes to obtain equivalent results.

OTHER ADVANTAGES

A reduction in sintering period makes possible a vastly increased production and a saving in consumption of electric power and controlled atmospheres. Distortion of objects during sintering is minimized.

There are no electrical resistors to burn out. Thus, very high temperatures are made possible. There is no insulation to absorb heat; the heat is concentrated in the material treated.

From the economic standpoint this development opens many new fields to Powder Metallurgy.

We suggest that you communicate with us for further information. Facilities are available for research and development work.

CHARLES HARDY, INC.

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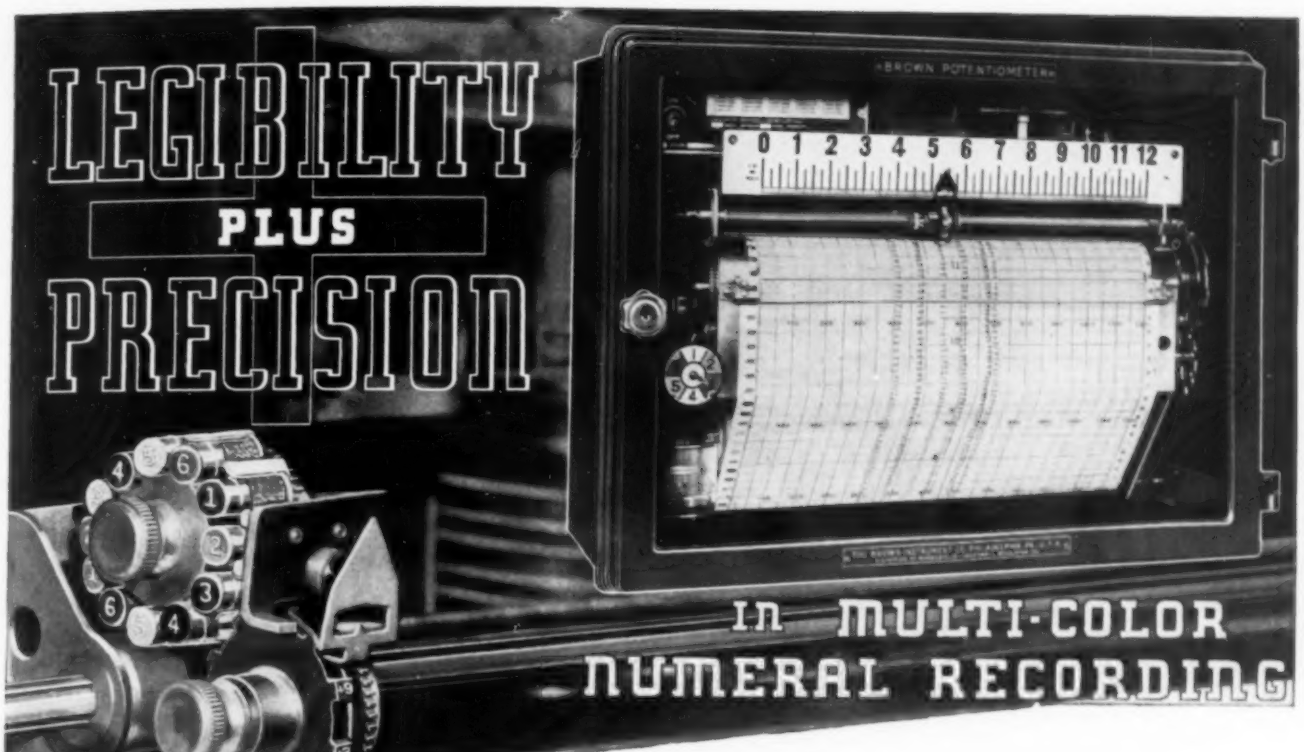
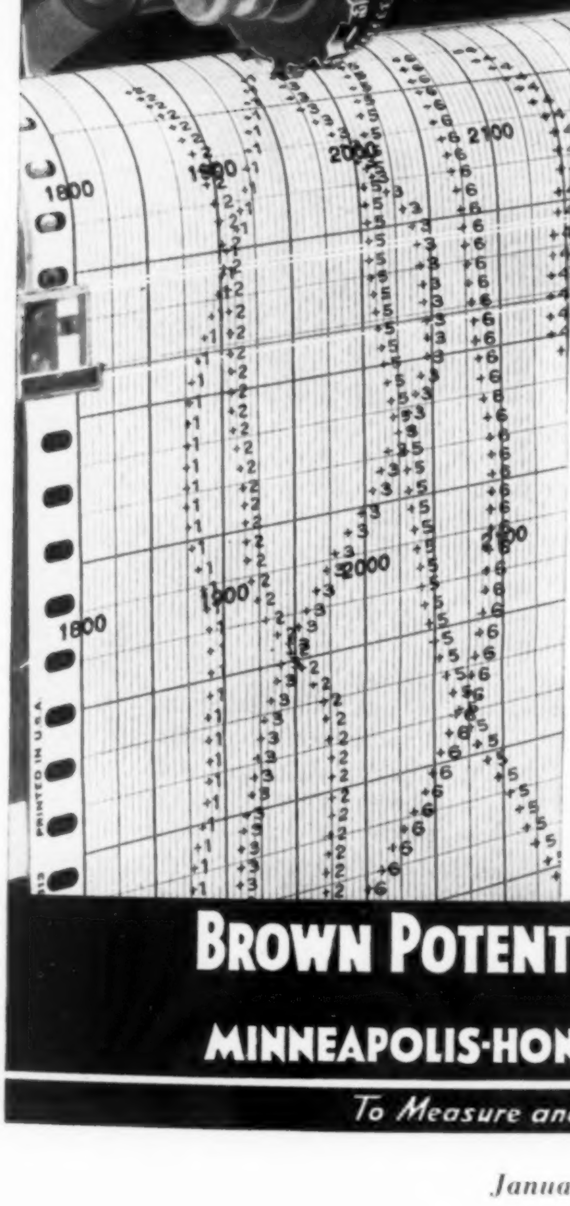
Exclusive Distributors of Hardy-Lepel High Frequency Sintering Furnaces and Lepel Electric Power Converters For Powder Metallurgy Applications; By Arrangement With the Ohio Crankshaft Company—Tocco Division.





No special skill is required to decipher the marks on a Brown Multiple-Recording Potentiometer Pyrometer chart record. Only one symbol—the + sign — is used and a number identifies the thermocouple from which the temperature recording is being made. Transparent, non-fading, colored inks further aid in rapid, legible reading of the individual records. Even where the numbers overlap, the records remain legible.

The Brown + symbol (an exclusive feature) in recording multiple-record temperatures, is no mere arbitrary, ornamental dot . . . it has a definite, practical significance. The vertical line of the + represents temperature, while the horizontal line is the time co-ordinate . . . the intersection of the two represents an actual point on the time-temperature curve.

The wide 12-inch chart, and the distinct imprint of the unique number print wheel make it possible to continuously record from two to six temperatures from as many different thermocouples.

Maximum legibility in reading the Brown Multiple-Record Potentiometer Pyrometer is further accomplished by a large, bold scale for long range sight reading.

There are many more refinements—each of real, practical value—fully explained in the Brown Potentiometer Catalog No. 1103—write for it. THE BROWN INSTRUMENT COMPANY, *a division of Minneapolis-Honeywell Regulator Co.*, 4503 Wayne Avenue, Philadelphia, Pa. Offices in all principal cities. Toronto, Canada: 117 Peter Street—Amsterdam-C, Holland: Wijdesteeg 4—Stockholm, 16, Sweden: Nybrokajen 7—London, England: 70 St. Thomas' Street, S. E. I.

BROWN POTENTIOMETER PYROMETER

AND

MINNEAPOLIS-HONEYWELL CONTROL SYSTEMS

To Measure and Control is to Economize

HARD CARBIDES

(Starts on page 61) lization unless careful attention is paid to the sintering temperatures. Other disadvantages accrue with extreme fineness of particle size. In many cases extreme fineness is unnecessary, since very low porosities are obtainable with relatively coarse particles if attention is paid to getting the proper size distribution.

Increasing cold pressures lead to marked improvements of hardness, although invariably a falling-off is noticeable at the highest pressures. Similar maxima are noticed with respect to sintering temperatures. No advantage is derived by sintering periods in excess of half an hour.

A survey of such phenomena and a study of the equilibria involved make it possible to choose for each combination of particle size distribution, die pressure, and sintering time a most suitable sintering temperature. For the very best results this temperature is fairly critical and necessitates close control — as are also die pressures and powder characteristics.

Other carbides (as well as other binders) were experimented with, and have commercial possibilities. The W_2C series is not so satisfactory as the normal tungsten type. Chromium carbides are unsatisfactory only in the tendency to cracking, presumably by oxidation. Molybdenum carbides oxidize too readily. The high commercial price of tantalum precluded an extensive examination of its carbide, although sufficient was done to confirm its high repute. Mixtures of titanium carbide and cobalt lead to compacts of great hardness if oxidation is prevented and sintering is performed at 1700 to 2000° C. Good results are obtainable with mixtures of tungsten and titanium carbides with cobalt.

No satisfactory method of bonding silicon or boron carbides for the formation of a cutting material was discovered.

Nitrides — An extensive series of tests was made upon various nitride mixtures. Nitrides were prepared by heating the metal powder in ammonia gas at appropriate temperatures. Several consecutive milling and heating stages were necessary; milling took place under hydrogen, and deoxidation in ammonia. Of more than 70 tests made, only 16 led to fairly satisfactory alloys with respect to hardness and density. These are summarized in the article. The average hardness of nitride compacts was far below that of carbides, possibly due to inadequate bonding and porosity rather than intrinsic softness of the nitrides themselves. Satisfactorily sintered and bonded, titanium and vanadium nitrides are expected to lead to high quality cutting alloys.

EXHAUST VALVES

(Continued from page 54) The valve is a hollow forging, sodium filled in stem and head, with a stem diameter of nearly $\frac{11}{16}$ in., nitrided for that part of its length that does not get "washed" by the hot exhaust gases. The valve seat is stellited. It was not so long ago that valves finally passed a 300-hr. test, to the gratification of all parties concerned. Today aircraft valves are operating 5000 hr. and beyond, and even then in excellent condition. Such an achievement represents a combination of materials, clearances, lubrication, alignment, and surface finish.

Credit is due to the British aero-engine manufacturers for adopting stellited valves and also the steel insert at the exhaust port, although stellite was first produced in the United States (the best of this material still comes from there) and was tried there some years ago on automobile valves.

Since British aero valves are not cooled by sodium in the head, but only in the stem, they run at fairly high temperature. In order to prevent scaling of the head (and liability to pre-ignition) some firms put a thin layer of stellite or "Brightray" over the whole of the exposed head surface. "Brightray" (80% nickel, 20% chromium) has been found superior for this purpose; treated valves come out of the engine at overhaul times looking comparatively clean.

Some successful tests have been made with complete valves of Brightray, forged. Due to relative softness, the stem wear was high. This might be overcome by a very high surface finish and by keeping the stem and guide clearances as small as possible; Brightray work-hardens to some extent and if a small initial clearance is given, it should settle down reasonably well after a few hours' running. The action would probably be equivalent to that of austenitic valves, such as D.T.D. 49-b, employed by some of the engine people without nitrided stems, and yet which perform quite satisfactorily. Although Brightray is more expensive than D.T.D. 49-b, a number of operations can be eliminated, particularly that of puddling a more heat resistant material on the seat and head.

Valve Seats — A valve seat insert should be fairly hard to avoid sinkage, and it should also be resistant to oxidation and corrosion. Fortunately, the working temperature of the insert does not approach that of the valve, and therefore it is not so subject to attack as the latter.

Good results have been obtained with some of the alloy irons, particularly those containing high percentages of chromium and molybdenum with Brinell number 500 and over, as cast. Such inserts are usually individually cast, *(Continued on p. 90)*

NOTES ABOUT CONTRIBUTORS

Robert Samuel Archer, past president ⊕, has crowded a wealth of metallurgical experience into his two score and three years. His principal interests have been in aluminum and steel, but he has made important contributions in other fields. His versatility is reflected in his attainments as author, inventor, executive and lecturer. Archer received his chemical engineering degree from University of Michigan, where he had the rare privilege of serving as assistant to the late Prof. Edward DeMille Campbell. In February 1919 he began his aluminum work in Cleveland and from 1925 to 1930 he was head of the Cleveland section of the Aluminum Research Laboratories. In 1930 he became director of metallurgy for A. O. Smith Corp., and since 1934 has been chief metallurgist, Chicago district, Republic Steel Corp. As co-worker with Zay Jeffries he proposed the slip interference theory of hardening and therefore is eminently fitted to summarize and review critically the Hardenability Symposium presented at the 1938 ⊕ convention.

⊕ ⊕ ⊕

Scholarship men, studying in foreign countries, have a habit of remaining there in after life. **C. A. Liedholm** is such a one. He received a scholarship from Jernkontoret (Swedish Iron Masters' Association) in 1928 for the study of electric steel melting in the United States. Since 1929 he has been with Jessop Steel Co., Washington, Pa., and is now metallurgical engineer in charge of physical and metallographical laboratory and research. His early education in Sweden was at the Filipstad Mining Academy; prior to coming to this country he was chemist for DeLaval Separator Co. in Stockholm and assistant metallurgist for the Hellefors Co. Since his arrival he has won a B.S. in Met. Eng. from Carnegie Institute of Technology.

"Graduate school activity at Penn State, with a Ph.D. in physical chemistry in view, ended in the latter part of 1927, when the lure of the Aluminum Co. of America proved greater," writes **John S. Marsh,** who prepared the report of the A.S.M.E. meeting appearing on page 51. His sojourn at the Aluminum Co. was brief and a year with Keuffel and Esser Co. followed. Marsh's definite hankering for metallurgy had its chance in 1930, in the early days of Alloys of Iron Research of the Engineering Foundation, when he became a member of the editorial staff; since 1933 he has been its physical metallurgist and associate editor. His share in the work of the Foundation has not been insignificant, as attested by the volumes on "The Alloys of Iron and Silicon", "Principles of Phase Diagrams", and "The Alloys of Iron and Nickel".

⊕ ⊕ ⊕

The versatility of **James L. Avis's** career is reflected in his letterhead — "Consulting Metallurgical Engineer, Research in Physical Metallurgy With Photomicrography, Production, Heat Treatment, Tests, Inspection, Causes of Failure of Metal Products". Trained at Virginia Polytechnic Institute, he served an apprenticeship in the B. & O. locomotive shops before being transferred to the laboratories where he learned routine testing and inspection along with considerable experimental work. Followed two years on automatic machine design at Winchester Repeating Arms Co. and eight years on the research staff of Robert W. Hunt Co. He then made connections with several mid-western foundries, both ferrous and non-ferrous, and had an opportunity to engage in research in physical metallurgy under the late Walter Rosenhain. His specialty, during the 15 years he has conducted his own business, has been in civil and admiralty litigation involving failure of equipment and machinery.

James L. Avis

Robert S. Archer

C. A. Liedholm

John S. Marsh


HAPPY NEW YEAR TO A. S. M. AND
SMOOTH SAILING FOR 1939.
The "Joseph Conrad," last full rigged ship under the American flag on the high seas.
FLOWN AND PHOTOGRAPHED BY H. H. H.
GENERAL ALLOYS COMPANY
BOSTON, MASS.
OLDEST AND LARGEST EXCLUSIVE MANUFACTURER OF HEAT & CORROSION RESISTANT ALLOYS

EXHAUST VALVES

(Starts on page 54) and must be ground all over.

Heat treated high speed steel is also very satisfactory and it can be machined before heat treatment. One of the leading American car firms has been using it for three or four years, and expects about 30,000 miles before valve attention is required.

Silcrome No. 1 is also a good insert material, machinable direct from bar stock, or, better still, forged individually.

Probably the most satisfactory insert is a steel ring with a stellited seating, the grade of stellite normally employed being No. 6.

If durability rather than cost is the ruling factor, then probably the best valve and insert combination is one having a stellited valve of austenitic steel and a stellited insert, both using No. 6 grade. Not only is it hard (approximately Rockwell C-45 to 50), but it is also very resistant to oxidation and corrosion. (Silcrome is somewhat tricky to stellite satisfactorily without fine cracks, and a grain growth which cannot apparently be rectified by subsequent heat treatment.)

During the last year or so Brightray has come to the fore in England for treating valves and inserts. It is a nickel-chromium alloy consisting roughly of 80% nickel and 20% chromium. So far it has only been used for aero-engine valves by well-known methods of welding-on for hard surfacing. Its melting point is somewhat higher than that of stellite, and care must be taken not to overheat the valve material.

Brightray is fairly soft, having a Brinell number of about 230, which is similar to that of D.T.D. 49-b valve steel, and it goes somewhat lower than this after puddling. Experience in aero engines has shown, however, that Brightray treated valves have a superior resistance to oxidation and corrosion. Despite its relative softness, it does not sink under the pounding of valve on seat; it is quite ductile and has little tendency to crack — a type of failure sometimes found in stellited seatings.

While inserts of aluminum bronze and also monel metal are satisfactory for aluminum cylinder heads, these have been discarded by the aero-engine manufacturers in favor of steel. The steels used are usually of the high expansion variety, such as "N.M.C." (Ni 12%, Mn 5%, Cr 3.5%, C 0.5 to 0.6%, Si 0.5%) or D.T.D. 49-b; however Silcrome has also proved to be quite satisfactory. Steels such as "N.M.C." and "49-b" have a high coefficient of expansion and poor thermal conductivity; inserts therefore run hotter, expand considerably and may overstress the aluminum surrounding it, and loosen. *(Continued on page 94)*

EXHAUST VALVES

(Starts on page 54)

The following combinations of valve and insert are worth considering. It should be said that in no case is the modern high duty engine using valves without stellite or Brightray seats.

Combination	Valve	Insert Material
A	D.T.D. 49-b Stellited	N.M.C.
B	D.T.D. 49-b Stellited	N.M.C. Stellited
C	D.T.D. 49-b Stellited	D.T.D. 49-b
D	D.T.D. 49-b Stellited	D.T.D. 49-b Stellited
E	D.T.D. 49-b with Brightray	Silcrome No. 1
F	D.T.D. 49-b with Brightray	D.T.D. 49-b

Combinations B and E are in service today in some of our most powerful aero engines. The author prefers E, because Brightray has superior corrosion resistance and appears less prone to guttering; furthermore, Silcrome has better heat conductivity compared to N.M.C. Silcrome is not so resistant as D.T.D. 49-b to hot and cold corrosion attack, and if any trouble is experienced from this source, F might be a suitable combination, although there are no indications, as yet, to show that Silcrome will prove to be unsatisfactory in this respect. American practice generally is along the lines suggested in C. N.M.C. has been proved a good insert material, but, of the two, D.T.D. 49-b is preferred, because it has superior resistance to hot corrosion attack and less tendency to loosen, in the case of the plain insert.

Stem Wear and Stem Guides — Great importance attaches to the stem of the valve, the guide and its cooling. The stem itself should be as hard as possible and have a good finish. The latter has been receiving much recent attention from American automotive engineers, where the practice of honing for valve stems, tappet faces and pistons is rapidly spreading.

The valve stem is honed by placing a number of valves horizontally on a wheel (rotating table), rotating the valves and the lower wheel, and giving an upper wheel both a circular and an oscillating motion along the valve stem.

The finish given to the bore of the valve guide is no less important than that of the valve stem. Reaming is the usual method employed in England; the Americans, however, consider broaching more satisfactory. The clearance between the valve stem and the guide should be as small as practicable. Not only does this assist in removal of the heat from the hot end of the valve stem, but modern experience has shown that a small initial stem and guide clearance results in a lower rate of wear between the two. *(Continued on page 98)*

EXHAUST VALVES

(Starts on page 54)

It is the author's experience that a hard valve stem and a hard guide surface is the best combination in order to combat wear. Hardness is not necessarily the only consideration; the structure of the material and its resistance to corrosion attack are very important.

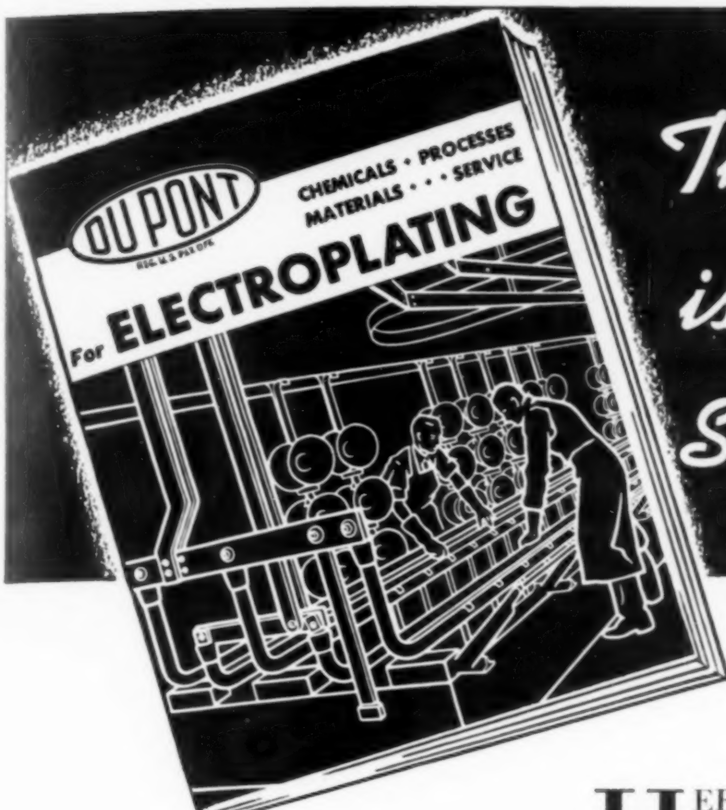
The valve guide material generally used in England is unalloyed cast iron, the guide being machined from a cast iron bar or from individual castings. A chemical specification is as follows: C (total) 3.5% max., C (combined) 0.5 to 0.8%, Si 1.8 to 2.5%, S 0.12% max., P 0.8% max. and Mn 0.4 to 1%. Individually cast this material has a very close grain with approximately 210 to 250 Brinell.

Picking up of the valve stem on the guide is sometimes experienced, often in motorcycle engines. In such cases the above material is hardened and tempered to about 400 Brinell. In some cases an iron containing 1 to 1½% nickel and 0.3 to 0.5% chromium is used for valve guides.

However, American developments suggest that the unalloyed cast iron guide will probably be superseded by the alloy irons of the nickel-chromium or nickel-chromium-molybdenum variety. The ordinary cast iron guide has a tendency to permanent growth at its flame-exposed end and also to bell-mouthing.

Colwell gives some interesting data on stem and guide wear with the alloy irons. He also mentions a nitri-castiron guide made from iron with an addition of chromium and aluminum: "It will harden from 700 to 900 Brinell by nitriding. The total nitriding depth will be 0.008 to 0.010 in. and have high hardness for the first 0.003 in. The material has shown remarkable properties as a cylinder sleeve and valve guide material which we attribute mostly to the hardness, some to its corrosion resistance. The surface structure is hard iron and chromium nitride needles, interspersed with graphite. The hard needles take the wear and the graphite feeds lubrication. . . . Field tests with these guides show six to ten times the life of a gray iron guide. The guide bore is honed, and clearance can be set close."

Aircraft engine valves are naturally very carefully guided and lubricated under pressure. The austenitic valve stems usually are fitted with thin bronze sleeves or guides which do not project above the boss. Minimum installation clearance is 0.0035 in. Actual operation of 3000 to 4000 hr. shows wear in many cases of only 0.001 in. on the nitrided stem, the maximum wear seldom being over 0.004 in.; the guide life guarantee is 1000 hr., and the guides usually last 1200 to 1400 hr.



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